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CHARLES D. WALCOTT, DIRECTOR

GEOLOGY

OF THE

CASTLE MOUNTAIN MINING DISTRICT

MONTANA

BY

WALTER HARVEY WEED

AND

LOUIS VALENTINE PIRSSON

WASHINGTON

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CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., February 1, 1896.

SIR: I have the honor to transmit herewith the manuscript of a report upon the geology of the Castle Mountain mining district of Montana, by Prof. L. V. Pirsson and myself. It has been prepared for publication as a bulletin of the Survey.

Very respectfully,

WALTER HARVEY WEED,
Geologist.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PREFACE.

This memoir is a general study of the region described, and not a detailed report. The field work upon which it is based formed a part of the work of mapping the areal geology of the Little Belt Mountains sheet of the Geological Survey. The topographic map, made in 1882 by the Northern Transcontinental Survey, is too small in scale and too general in character to warrant more detailed work; but as the facts obtained are of interest, and the region is one of economic importance, it has been considered worthy of a special treatment.

The cessation of mining and consequent inaccessibility of the mine workings prevented any underground study of the ore deposits, so that, with the exception of those concerning the Cumberland mine, the facts given have been derived from a study of the surface alone.

The field work was done during the summers of 1892 and 1893, Professor Pirsson accompanying the writer during the latter year and studying the field relations of the rocks with him. The authors wish to acknowledge their joint indebtedness to the Sheffield Scientific School of Yale University. The petrographical and chemical investigation of the igneous rocks was carried on in the mineralogical-petrographical laboratory of the Sheffield School, and the authors' cordial thanks are due for the facilities and many courtesies extended to them during the progress of the work.

W. H. W.

GEOLOGY OF THE CASTLE MOUNTAIN MINING DISTRICT, MONTANA.

By W. H. Weed and L. V. Pirsson.

CHAPTER I.

INTRODUCTION.

GEOGRAPHY.

In the State of Montana the Yellowstone River on the south and the encircling Missouri on the west and north inclose a part of the Rocky Mountain region that is formed of two main chains of mountains long known as the Big Belt and the Little Belt ranges. These ranges have a general north-and-south trend; the Big Belt lies to the westward, and is separated from the Little Belt Range by the broad, intermontane valley of Smith River. The area whose geology is described in the present bulletin is a portion of this region, and all parts of it are more than 5,000 feet above sea level. (See fig. 1, p. 16, showing location of district.) Within it lies Castle Mountain, a flat-topped elevation, whose crown of ruin-like crags, rising above the black pine forests that cover its summit, at once suggests its name. This mountain mass is a distinct geographic unit, not being directly connected with either of the above ranges. On the south it is separated from the broad valley of the Yellowstone by that imposing group of lofty peaks known as the Crazy Mountains; northward the dark, pine-clad plateaus of the Little Belt Range rise against the sky. It thus forms a distinct link in the chain that defines the eastern limit of the Rocky Mountain cordillera, from the base of which the Great Plains sweep in unbroken continuity to the prairies of Dakota.

Two rivers, branches of the Missouri, have their sources partly in its springs and snow banks. One of them is Smith River, the two branches of which encompass it on the west and north. The stream formed by their union runs northward between the two Belt ranges, until, passing through a deeply cut gorge, it enters the open plains country and flows into the Missouri above Great Falls. The other stream, the Musselshell, whose forks inclose the mountain on the east and south, flows several hundred miles through the arid wastes of the broken plains country, and joins the Missouri above its confluence with the Yellowstone.

The area represented by the accompanying map (Pl. I), which includes Castle Mountain and parts of the adjacent valleys, is limited by the meridians 110° 15′ and 111° and the parallels 46° 20′ and 46° 26′, and is in Meagher County, Mont.

There are few areas of equal size in the Rocky Mountain region which present so wide a range of rock formations. An uplift, involving the entire series of stratified rocks known in the northern Rocky Mountain district, has been the site of a volcano which subsequent erosion has thoroughly dissected, exposing a variety of intrusive igneous

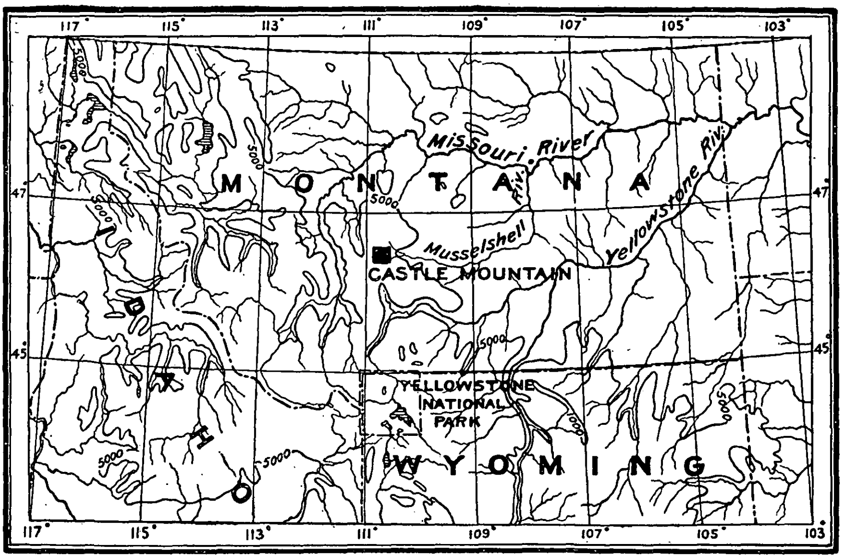

Fig. 1.—Index map showing location of Castle Mountain district in Montana.

rocks with associated lava flows and fragmental deposits, together with the various stratified rocks that formed the foundation of the mass. As the mountain is thus of great geological interest, and contains, moreover, important deposits of silver-lead ores that have made its name familiar to the mining world during the past few years, it was made the object of especial study in the work of mapping the areal geology of the Little Belt Mountains atlas sheet of the United States Geological Survey. The small scale of the map and the general character of the topography did not, however, permit a closely accurate outlining of the geology, and this bulletin should be regarded as a general description rather than as a detailed study of the mining district.

By reason of its geographical position at the head of the arid Smith Valley, the mountain acts as a condenser for the moisture gathered farther westward. Snowstorms are frequent as late in the season as

TOPOGRAPHY BY NORTHERN TRANSCONTINENTAL SURVEY 1882-83

JULIUS BIEN & CO. N.Y.

TOPOGRAPHIC MAP OF CASTLE MOUNTAIN DISTRICT, MONTANA

CONTOUR INTERVAL 200 FEET

Scale

0 2 4 6 8 Miles

1896

June, and as early as September, and the annual snowfall is heavy. Through the brief, hot summer that scorches the adjacent valleys the mountain summit is the focus of many violent thunderstorms, and in consequence of the moisture from them the slopes are bright with verdure.

The ore deposits of Castle Mountain made its name well known in the Northwest. Their discovery brought into a region previously devoted solely to stock raising the feverish activity of mining enterprise, which was succeeded, however, on the cessation of silver production, by the present period of inaction. The most important town within the limits of the map is White Sulphur Springs, the county seat of Meagher County. It is a thrifty, pleasing little city of 2,500 inhabitants, and owes its name and location to the hot springs at the western base of the mountain. It is one of the oldest towns of the State, and is as yet without direct railroad communication, though numerous stage lines radiate from it in every direction, taking daily mails to Townsend, on the Northern Pacific Railroad, 40 miles distant, and to Neihart, the terminus of a branch line of the Great Northern. The mining settlements of Castle, Robinson, and Blackhawk, situated on the flanks of the mountain, as shown on the map, were for a while very active, important places, but they were wholly dependent upon the mining industry, and consequently they are now nearly deserted. The completion of a railroad now under construction from Toston, on the Northern Pacific Railroad, will bring these towns in direct communication with the mining and smelting centers of the West. Good wagon roads also afford direct communication with Livingston to the south, White Sulphur Springs to the west, and Martinsdale to the east. The high elevation of the surrounding country and the rigorous climate are not favorable, however, for agriculture, and the ranches now found in the district are devoted to the raising of hay for winter feed of sheep and cattle.

PREVIOUS EXPLORATION.

The pioneer explorers of the Northwest, Lewis and Clarke, named upon their map both Smith River and the Musselshell, but their routes were north and south of this region. In 1853 Lieutenant Mullan, of the Pacific Railway exploring expedition, followed up the north fork of the Musselshell to the head waters of Smith River, and passed down that stream to the westward. Captain Clift, in his exploratory march across Montana in 1869, also followed this route, which forms a natural highway from the mountain region to the plains country eastward. In 1873 Captain Ludlow, accompanied by Messrs. G. B. Grinnell and E. S. Dana as geologists, followed the same route, which afterwards became a part of the stage route from Carroll, the head of steamboat navigation on the Missouri, to Helena. These geologists noted the salient features of the geological structure and the character of the rocks along the north forks of Musselshell and Smith rivers, and recognized the eruptive nature of the mountain mass, whose picturesque crags and towers form so prominent a feature, as seen from White Sulphur Springs. These observers passed up the south fork of Smith River on their way to the Yellowstone Park, and returning followed down the south branch of the Musselshell. In their report[1] they give brief notes of the geology along their route.

In 1880–81 the geologists of the Northern Transcontinental Survey, organized by the Northern Pacific Railroad for an economic survey of the territory tributary to the railroad, examined the country adjacent to Castle Mountain in their search for coal. In the only published reports of this organization[2] the mountain is not mentioned, but its geological nature is indicated upon the accompanying maps, and Mr. G. H. Eldridge gives a section of the rocks exposed at the east end of the mountain.[3] Mr. J. E. Wolff, then of the same survey, in his paper on the Crazy Mountains,[4] mentions the general structure of the mountain and the eruptive character of Black Butte, an outlying elevation. That veteran geologist and keen observer, the late Prof. J. S. Newberry, described the rocks about White Sulphur Springs,[5] but did not visit Castle Mountain itself.

It is apparent that in the hurried trips of these earlier explorers through the circumjacent valleys the interesting character of Castle Mountain was only surmised. Although the country about it was sparsely settled by sheep and cattle ranchmen, the mountain was visited only to procure necessary timber or firewood. Prospectors, attracted by the Copperopolis veins, may have visited its slopes and explored its gorges, but it was not until the discovery of the rich ore body of the Cumberland mine, above the town of Castle, that the mountain itself attracted any attention. An immediate rush for the "new Leadville," as it was fondly called, followed this discovery. Sheep herders, ranchers, nearly every one from the surrounding valleys, took up claims and built cabins upon the mountain slopes. Roads were cut through the forest and graded across steep gulches, and labor and money were lavishly spent while the "boom" lasted.

The future of the district is dependent upon the price of silver; under conditions prevailing during 1893 and 1894 the mines could not be profitably worked, and the mountain towns were deserted for more promising localities.

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[1]Reconnoissance from Carroll, Mont., to Yellowstone Park, U. S. War Dept., Washington, 1876.

[2]Coal fields of the Northwest: Tenth Census, Vol. XV.

[3]Ibid., p. 740.

[4]Notes on the Petrography of the Crazy Mountains and Other Localities in Montana, Heidelberg, Germany, 1883, p. 3.

[5]Notes on the geology and botany of country adjacent to Northern Pacific Railroad: Annals N. Y. Acad. of Sci., Vol. III, No. 8, p. 242. See also Am. Jour. Sci., 3d ser., Vol. XLI, 1891, p. 191.

CHAPTER II.

TOPOGRAPHY.

THE MOUNTAIN.

Castle Mountain is an elevated mass rising to a height of 8,600 feet above sea level, its highest point being 3,600 feet above the neighboring valleys. Seen from the lower valleys, it is a broad, flat-topped mountain mass, its upper slopes densely wooded, with castellated masses of granite rising above the pines. Though lacking in bold, jagged peaks, this mountain presents a pleasing type of scenery, while from its slopes the views of neighboring ranges are very impressive. The deep gorges that score the mountain and the upland parks and summit meadows are extremely picturesque.

The valley drained by the forks of the Musselshell and the Smith rivers sharply defines the mountain as a single mass. It consists of a main and higher western portion joined by a trenched plateau with an eastern limestone ridge, which rises abruptly from the prairie terrace between the forks of the Musselshell. In rude outline, as defined by the surrounding valleys, the whole mass has the shape of a dumb-bell.

The main summit, whose highest point is designated Elk Peak on the map, is a thickly timbered, nearly level area, defined by slopes sinking abruptly to lower mountain benches, or by the walls of sharply incised mountain amphitheaters, in whose snow banks the largest streams have their sources. Radiating from the summit, the streams have cut deep mountain gorges, the ridges between being flat-topped. These flat summits are very characteristic of the mountain top. Alpine benches, ice-swept upland terraces, and moraine terraces are everywhere prominent.

In the eastern part of the mountain—formed of the extended ridge previously mentioned—the heavily bedded Paleozoic limestones dominate the topography. In them the streams have cut narrow gorges with pinnacled walls, which contrast sharply with the gentle valley slopes, where the rocks are shales or Mesozoic sandstones. The larger topographic features of this eastern part of the mountain are of structural origin.

The whole mountain is very generally outlined by the boundary of the Cretaceous rocks or the soft shales of the Algonkian. Where the readily eroded beds of these periods occur, unaltered by local metamorphism, the slopes are abrupt down to the low-lying basins cut in them. The details of topographic configuration are very largely dependent upon the nature of the rocks, whose great diversity produces widely differing types of scenery. The gently contoured dark slopes of Algonkian slate are thus in great contrast to the cliffs or towering ledges of light Carboniferous limestone, the great débris slopes of porphyry, or the low relief of Cretaceous shale. Upon the mountain flanks outward-dipping beds have in a few places been eroded into the revet hills, or hogback ridges, so common along the foothills of the Rocky Mountains. Volcanic dikes or sheets, when intruded into the readily eroded Cretaceous strata, are generally conspicuous, either as imposing walls of rock or as sharp comb ridges. (See Pl. II.) West of the mountain the slopes end abruptly on the broad, very gently sloping surface of the valley of South Smith River, once a lake bottom, but now an arid flat, with scanty vegetation. Copperopolis Valley, as seen from Volcano Butte, a prominent hill in its center, has a nearly level floor formed by a basaltic lava flow.

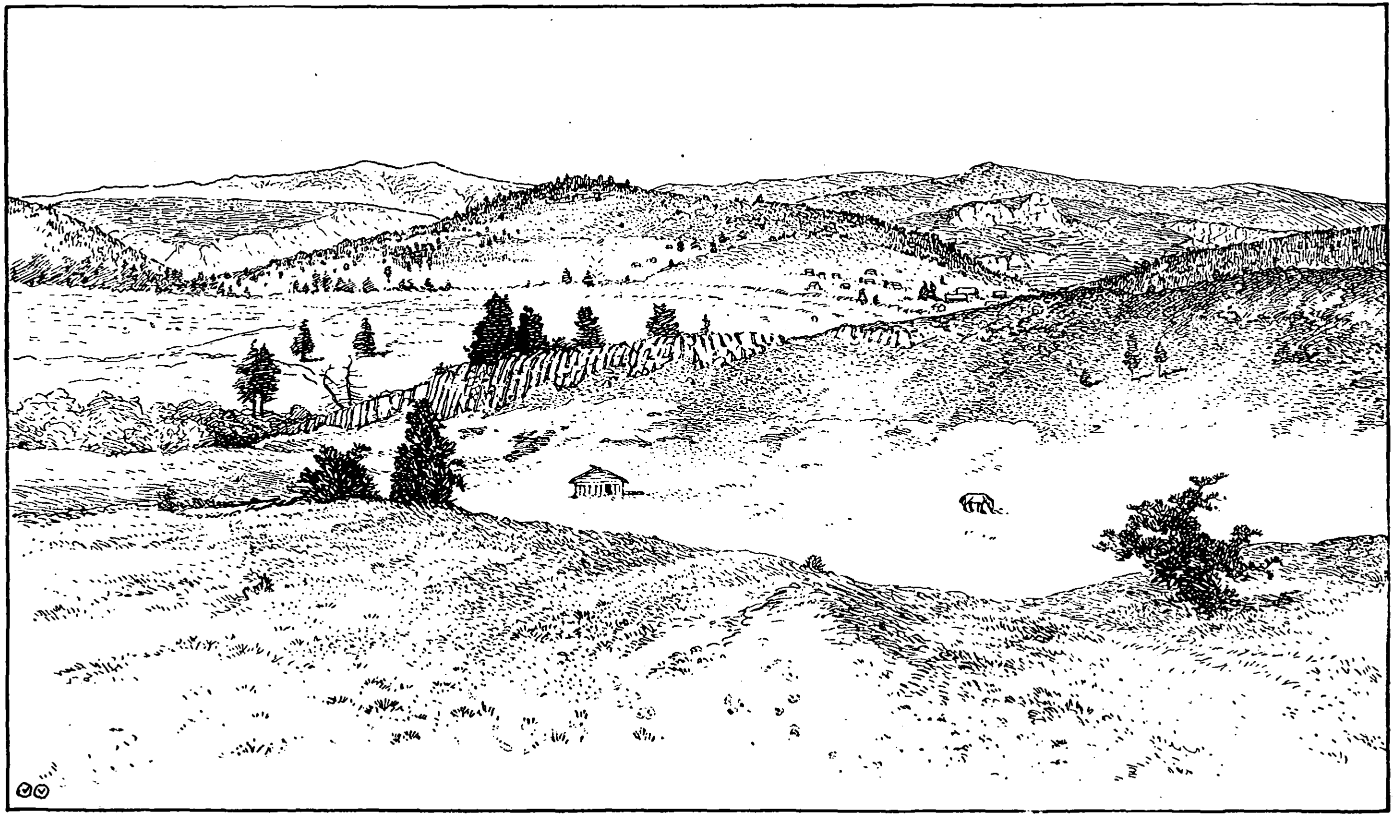
STREAMS.

A glance at the map of Castle Mountain shows that the area is drained by numerous streams, head-water branches of the Musselshell and Smith rivers. These streams, with few exceptions, have their sources in clear and cold springs, high up on the flanks of the mountain. When reenforced by the melting snows of early summer they flow down as impetuous torrents, sink from sight beneath the gravel beds of their lower courses or in the underground channels of the limestone areas, and often reappear as enfeebled creeks, whose murky currents, meandering across the level lower valleys, are in marked contrast to the sparkling waters of the mountain area.

The larger streams, Warm Spring Creek on the south and Willow and Fourmile creeks on the north, head in amphitheaters cut back to the highest summits of the mountain. All these flow in V-shaped gorges, whose varying scenery depends upon the nature of the rocks cut by them. The west slopes of the mountain are drained by small brooks, of which only Cottonwood has cut any distance into the mountain. It is the only creek which sends its water over the valley plain.

To the east, the sharp limestone ridge forming the end of the mountain is scored by small, normally dry drains debouching upon the Cretaceous plain.

The Musselshell heads in an amphitheater south of Elk Peak. The creek is there known as Warm Spring, the constant temperature of its tributary springs melting the snow banks of the valley. Flowing in a gorge whose stream bed is 1,000 feet below the mountain benches on either side, with heavily wooded, spring-wetted bottom, this stream passes into a broader valley cut in Cretaceous rock, and then enters a shallow canyon with walls of 25 to 75 feet of soft sandstone or shale.



CASTLE MOUNTAIN, FROM THE SOUTH, SHOWING INTRUSIVE SHEET IN FOREGROUND.

Joined by Bozeman Creek and other small streams, it turns eastward, and becomes the South Fork of the Musselshell. Alibaugh and its branches—Hamilton, Hensley, and Robinson creeks—are similar in character, and flow over bowlder-choked channels through old glacial moraines to unite with the Musselshell.

Bonanza Creek, heading in the beautiful mountain park near Blackhawk, cuts an impassable canyon through igneous rocks and white Paleozoic limestone, and reaching Mesozoic shales turns abruptly to the south and enters a broad basin, where its waters are taken for irrigation by the ranchmen of the valley.

The largest branch of the North Musselshell comes from the slopes of the Little Belt Range north of Castle Mountain, though Flagstaff Creek, whose head-water branches have cut picturesque canyons in the heavily bedded Paleozoic limestones of the eastern part of the mountain, is an important tributary. Checkerboard Creek, heading in the springs near Blackhawk and the gorges cut far back toward the mountain summit, is the largest tributary of the North Musselshell. A noticeable peculiarity of this stream, explained later, is its abrupt bend to the east, cutting a deep cliff back of Copperopolis Hill, instead of crossing the low, easily eroded country to the north to join Smith River.

Smith River is a considerable stream, whose chief tributaries are Fourmile and Willow creeks. The first of these is one whose waters join the river only in time of flood. Near its sources the streams forming the creek carry considerable water and flow impetuously over rocky channels, whose deep pools contain an abundance of trout. Its westerly branches head in copious springs issuing from the lower parts of drainage valleys devoid of stream channels since the disappearance of the ice sheets that once covered the mountain.

South Smith River has a small and sluggish current of turbid water. It heads in a basin on the south flank of the mountain and meanders through the level valley plain to join the northern fork below White Sulphur Springs.

CHAPTER III.

STRUCTURAL GEOLOGY AND GEOLOGICAL HISTORY OF CASTLE MOUNTAIN.

GENERAL GEOLOGICAL STRUCTURE.

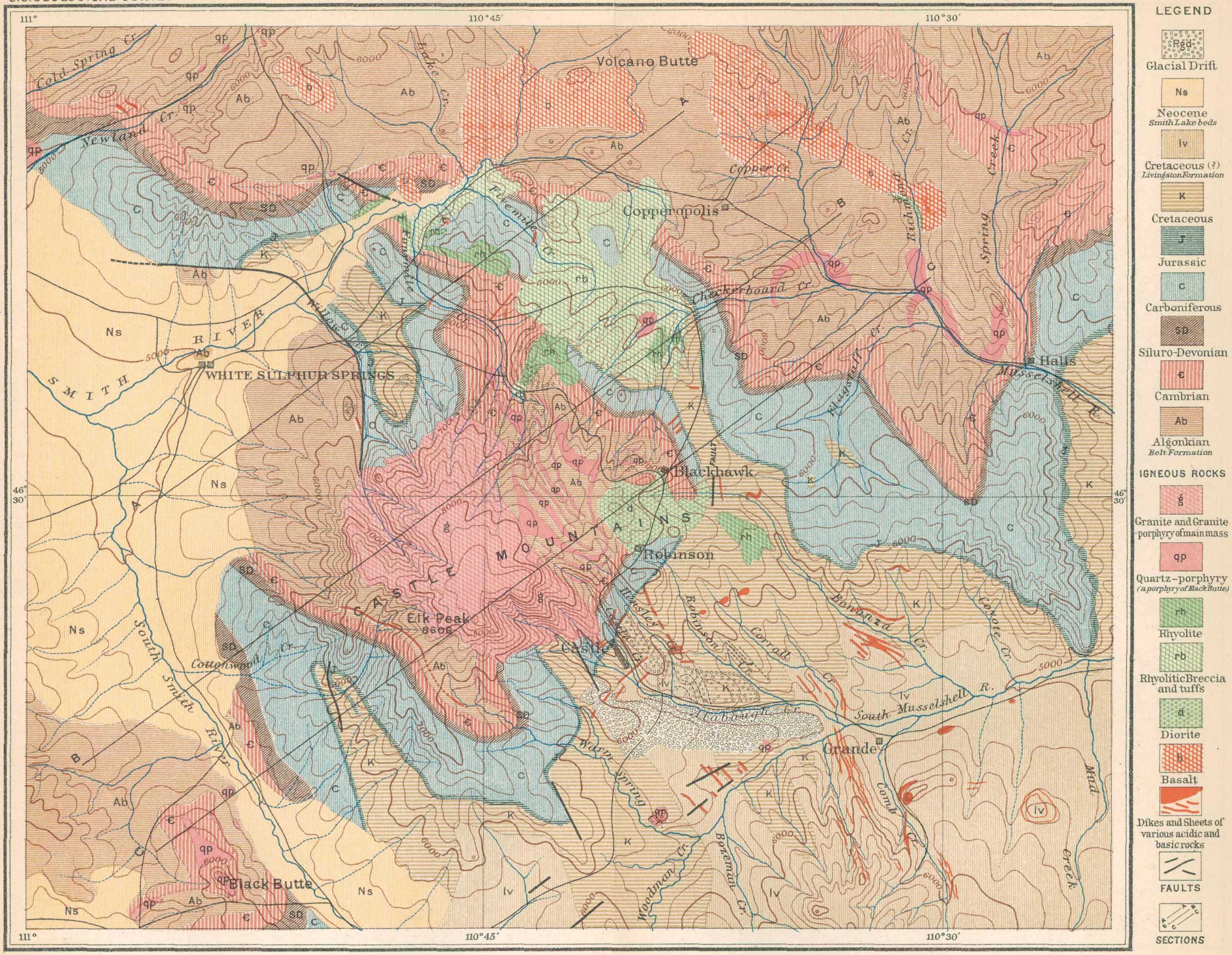
Castle Mountain is a dissected volcano. Degradation has laid bare its structure, yet has not entirely removed the surface rocks that are the peculiar products of volcanic activity. The geological map (Pl. III) shows clearly that the great granite mass that forms the mountain summit, and also the smaller body of diorite to the east, breaks through folded sedimentary rocks. On the northern flanks of the mountain remnants of lava flows and of fragmental deposits, and to the south morainal débris, partly obscure the structure of the sedimentary rocks.

The mountain forms a part of the Rocky Mountain front, and its larger structural features belong to the general system of plications that characterize the outer margin of the cordillera region. The eastern part of the cordillera is in Montana formed of two main areas of uplift with minor folds between them. The first or southern region composes the Beartooth and Snowy ranges, and extends northward from Wyoming, forming the mountainous tract north of the Yellowstone Park. It is a broad anticlinal uplift, having a nucleus of Archean rocks, generally denuded of their former covering of Paleozoic strata and modified by faulting. The second area lies to the northwest of the first, and is formed by the broad anticlinal folds of the Belt ranges, whose nucleal core is made of a group of Algonkian rocks that do not occur in the southern ranges.

About the margins of both these areas of uplift the Paleozoic and Mesozoic rocks are plicated in a series of minor undulations presenting varying features of interest.[1] Castle Mountain occurs on the border of this second great area of uplift, its folds forming the geological connections between the two Belt Mountain anticlines.

In its general structural features Castle Mountain is a part of the great anticlinal folds of the Belt ranges. The Algonkian (Belt) area of its western slopes (and the vicinity of White Sulphur Springs) is part of the eastern end of the Big Belt anticline. The anticline that forms the southwestern portion of the mountain is one of the small sharp folds that mark the dying away of this greater fold. The northern part of the mountain is clearly part of the broad anticlinal area of

[1] See Livingston folio, showing échelon folds of this vicinity: Geologic Atlas of the United States, folio 1, United States Geological Survey, Washington, D. C., 1894.



TOPOGRAPHY BY NORTHERN TRANSCONTINENTAL SURVEY 1882-83

GEOLOGY BY WALTER HARVEY WEED

GEOLOGICAL MAP OF CASTLE MOUNTAIN DISTRICT, MONTANA

CONTOUR INTERVAL 200 FEET

Scale

0 2 4 6 8 Miles

1896

JULIUS BIEN & CO. N.Y.

the Little Belt Range, laid bare by erosion, exposing the nucleal rocks of Belt age in Volcano Valley, a minor transverse fold forming the eastern part of the mountain mass.

PROMINENT ANTICLINES.

An inspection of the geological map (Pl. III), shows that there are two prominent anticlines, on the east and west sides of the mountain respectively, inclosing the main mountainous area between them. The axes of these anticlines have a general northwest and southeast direction, and pitch to the southeast, where the sharply folded Paleozoic limestones dip steeply beneath a great thickness of Livingston beds. Between these two dominant anticlines the sedimentary rocks show several minor folds, some of which are broken by the intrusive rocks. The anticline forming the eastern part of the mountain is typical of the Belt Mountain region. It is a normal fold that forms a lateral offshoot of the Little Belt anticline. The structure is simple, and by itself offers no feature of especial interest. Volcano Valley has been eroded in the Belt shales that form the nucleus of this fold, while the heavy limestone series constituting the resistant member of the plicated beds dips away on either side and forms the sharp plunging point of the anticlines. This fold, as seen in horizontal projection, is V-shaped, rapidly widening to the north, and as the tilted axis rises northward the fold is faulted along the foot slopes of the Little Belt Range. The core of Belt shale is encircled by the Paleozoic limestones, that extend along the northern flanks of Castle Mountain from the Musselshell Canyon (Hall's) to near White Sulphur Springs. The relations of this fold to the Little Belt Range are clearly shown in Sections C-D and E-F, Pl. IV. The northern side (or limb) of the anticline is seen to be faulted at the base of the Little Belt Range, the fault dying out to the southeast in the normal fold.

The second of the two larger anticlines of the district is abruptly cut off by the granite intrusion of Elk Peak. This fold forms the western flanks of Castle Mountain, and its southern extension is dissected by the branches of Warm Spring Creek. While the Miocene lake beds very generally conceal the Paleozoic rocks southeast of the Castle Mountain area, and thus obscure the relations of this fold to the Big Belt Range, it is quite clear from the studies made in the field that the fold is one of the lesser plications that form the southeastern end of the Big Belt anticline. This Warm Spring Creek anticline is overturned to the east. The granite intrusion that forms the mountain summit replaces the northern part of the fold, leaving only the extreme southern end intact. Its relations to the granite are clearly shown in Sections A-B and E-F, Pl. IV. The overturned structure of the end of the fold is shown in the folded beds cut by Warm Spring Creek. North of the granite area this fold, whose continuity has been destroyed by volcanic agencies, is clearly continued in the Willow Creek fault.

MINOR FOLDS.

Between the two larger anticlines already noted the sedimentary beds are flexed in several minor folds, whose axes are in general parallel to the major plications. Thus a narrow synclinal basin about the forks of Flagstaff Creek separates the flanks of the larger fold to the east from a sharp and narrow anticline to the west, through which the forks of Flagstaff have cut narrow gorges that display excellent sections of the appressed fold. This plication fades out to the northwest, passing into the flanks of the Volcano Valley fold before reaching the canyon of Checkerboard Creek. Its summit beds form the high upland lying between the eastern ridge and the main mountain mass of Castle Mountain, the higher limestones being flat and forming grassy plateau summits. In the stream gorges cut across this fold the dependence of the

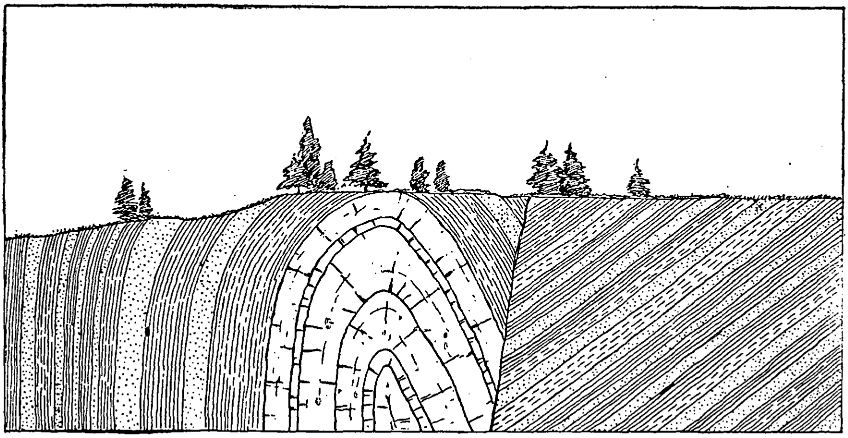
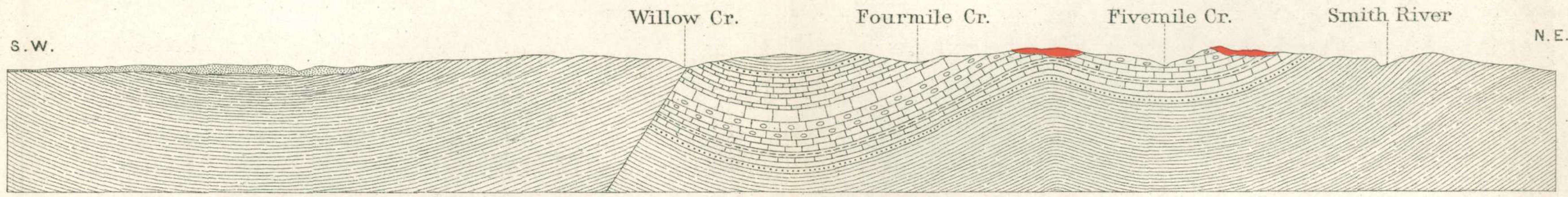


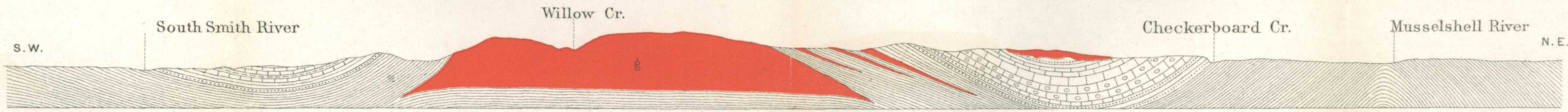
FIG. 2.—Fold and fault exposed on Flagstaff Creek.

character of the fold upon the nature and material of the beds is strikingly shown; the contrast is especially marked between the massive limestones and the softer Mesozoic shales and sandstones.

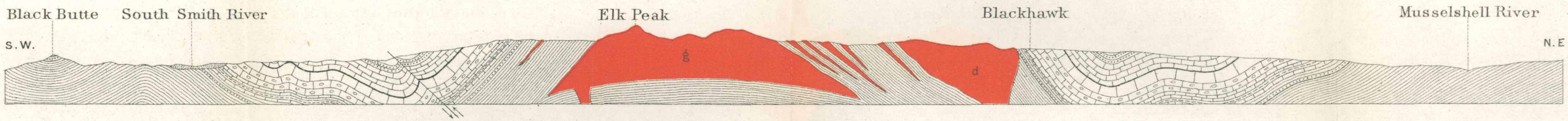
Northeast of the granite mass of Castle Mountain an area of Belt shales, largely metamorphosed and altered by intruded sheets of porphyry, represents the nucleus of another anticlinal fold. This fold is, however, largely destroyed. It is broken by the diorite intrusion along its eastern flanks, and its western half is entirely destroyed by the granite stock. Only upon the northeastern flank do the imbricated beds of limestone that dip away from the central core of Cambrian shales maintain their unaltered position and character. Between Robinson and Castle a portion of the eastern flank of this fold still remains, the rocks being those in which the ore deposits of this vicinity are found. Below Blackhawk, Bonanza Creek cuts a small anticline and exposes a core of Carboniferous limestone, with a strike fault along the western side, the section being shown in the accompanying diagram, fig. 2.



SECTION A-A



SECTION B-B



SECTION C-C

GEOLOGICAL CROSS SECTIONS, CASTLE MOUNTAIN.

Scale

0 2 4 6 8 MILES.

JULIUS BIEN & CO. N.Y.

The southeastern portion of the map (Pl. I) shows a broad valley basin inclosed between Castle Mountain and the slopes of the Crazy Mountains. This valley area is eroded in the later Cretaceous rocks which occupy the center of a broad synclinal basin. To the north the syncline forms the highland meadows east of Blackhawk, and only the earlier members of the Cretaceous—the Benton and Dakota—remain. In the main syncline, however, these beds are seen only about the borders of the basin, the center being occupied by Livingston beds, showing numerous minor plications. The accompanying diagram (fig. 3) shows these minor foldings along the Musselshell from Warm Spring to Alibaugh creeks.

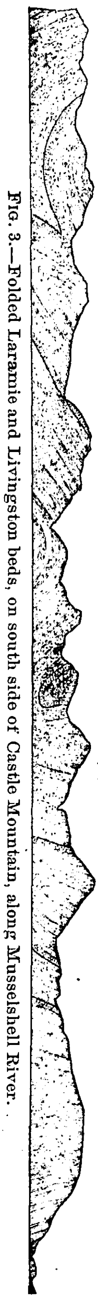


FIG. 3.—Folded Laramie and Livingston beds, on south side of Castle Mountain, along Musselshell River.

FIG. 4.—Folded Paleozoic strata, on west slope of mountain, near Cottonwood Creek.

Only the extreme point of the long syncline between the Crazy Mountains and the Bridger-Sixteenmile uplifts comes within the limits of the map. This is eroded into the valley in which the South Fork of Smith River takes its head, the beds forming the prow of a typical "canoe" fold.

Southwest of Elk Peak, the culminating point of the Castle Mountain mass, the lower slopes and valley bench-land are underlain by folded Paleozoic beds. The accompanying diagram (fig. 4) shows the section across these beds. The erosion of the valley of Smith River shows another flexure of which Black Butte is the southwest flank.

But one other fold remains to be noted. This is the shallow syncline whose present surface shows Benton shales, and forms a shallow basin defined by Dakota quartzite that lies between Fourmile and Willow creeks. The general trend of the axis conforms to the other folds, but a transverse puckering extends the syncline eastward at right angles.

In these folded sedimentary strata the igneous rocks occur as intrusive stocks, with apophysal sheets, and as dikes, filling fractures of the folds. The central stock or core of granite breaks across the Warm Spring fold and Willow Creek fault. It appears to have had but little, if any, dynamic effect, the adjacent folds preserving their original atitude, except on the northeast, where numerous intruded sheets have caused a local thickening and uplift. It does not seem probable that such a large body can extend downward with unaltered dimensions, and it is shown in the cross sections as a laccolite-shaped mass.

Section C-D (Pl. IV) cuts this granite mass transversely and shows what is believed to be its relations to the rocks through which it breaks and its connection with the surrounding sheets of porphyry.

The occurrence of the igneous rocks is so exhaustively treated in a subsequent chapter that any further mention here of their relations is unnecessary.

GEOLOGICAL HISTORY.

The geological history of the Castle Mountain area embraces an enormous period of time, extending from Algonkian to the present. The history of Castle Mountain itself is much briefer, beginning with the uplifts of the front ranges at the close of the Laramie epoch. The history is therefore properly divisible into two great periods. The first is the period during which the sedimentary rocks were formed; the second, that in which these rocks were folded, faulted, eroded by streams and atmospheric agencies, broken through by volcanic intrusions and covered by fragmental volcanic rocks and tuffs, and later the whole complex carved into its present form.

The history of the sedimentary rocks is that of the northern Rocky Mountain area, of which the Castle Mountain region forms so small a part. The earliest rocks, constituting the Belt formation, are shales, impure limestones, and sandstones. They are all shallow-water or shore deposits. The sandstones are sometimes ripple-marked and are of littoral origin. The contrast in character of the sediments of the Belt and all succeeding formations, together with the transgression of the sea at the beginning of Middle Cambrian time, shows a period of rest between the Belt and Flathead epochs.

At the close of the Belt period, which was one of slow subsidence and correlative deposition, the sea bottom rapidly sank and the ocean waters transgressed the low-lying lands. This depression is indicated by the Flathead quartzite, which is formed of Archean materials. Together with the succeeding micaceous shale, the rocks indicate offshore deposits, entombing in the ocean floor the forms of marine life that then flourished and forming thin beds of limestone.

The conglomerates that occur in the Upper Cambrian sediments show shore conditions; the pebbles are of limestone, differing from any of the beds of the Belt formation, but quite like those of the Flathead. It must be inferred, therefore, that they were derived from uplifted and exposed beds of Cambrian age.

The limestones representing the period of time from later Cambrian to the beginning of Carboniferous time show that this unstable condition of land and sea continued. Succeeding the quiet limestone-making period, represented by the Jefferson, the arenaceous limestones, carrying corals, show shoaling waters, in which the argillaceous limestone beds of the Devonian were laid down.

With the earlier Carboniferous a period of regular marine sedimentation began, which went on uninterruptedly through a relatively long period of limestone deposition, while the shore line retreated inland; this was followed by elevation of the sea bottom during a period represented by the Quadrant formation, whose alternations of red gypsiferous sands and argillaceous shales, with occasional lenticular beds of pure limestone, show shallow reaches and inclosed basins along the oceanic border. The fossils, indeed, indicate a fauna living in a sea not favorable to its full growth and development.

Succeeding the Carboniferous, there was a gentle uplifting of parts of the ocean floor. The total absence of Upper Carboniferous sediments, as shown by the St. Louis facies of the fossils of the highest Carboniferous beds found, together with the character of the rock forming the upper part of the terrane, shows a period of nondeposition at the close of Lower Carboniferous time. The conglomeratic character of the base of the Jurassic and the comminuted shells clearly show erosive processes, a conclusion confirmed by observations in neighboring regions.

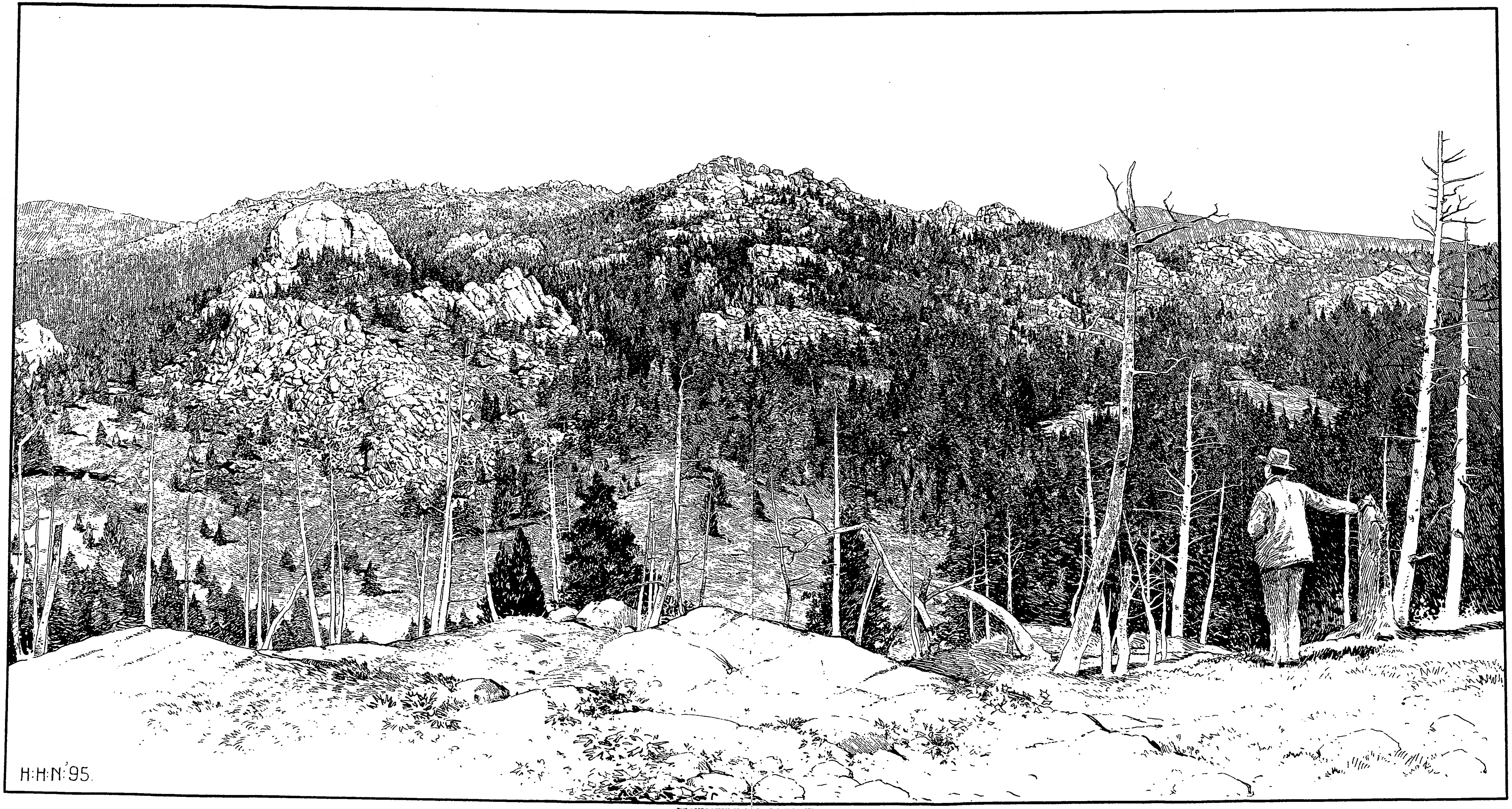
The lowest Cretaceous beds are sandstones and clays, which, with the coal seam so constantly found at this horizon, indicate low-lying marshy shores and extensive mud flats. The strata afford no record of the long period of Lower Cretaceous time that intervened between the deposition of the Kootanie and the Dakota beds. The succeeding Dakota sandstones show the littoral deposits formed in the first part of a continued subsidence during which depression and deposition were nearly equal. The well-defined formations into which the Cretaceous is divisible in the plains country are here difficult to recognize. The sediments were deposited near the Cretaceous shore-line, and the epoch throughout was one of very slow and gradual subsidence in which the deposition of sediments seems to have nearly kept pace with the sinking of the sea bottom. The oscillations of level produced rapidly alternating strata, whose history can be correctly read only when compared with that of the sections farther from the shore. Gradually shallowing seas followed, and at the beginning of the Laramie, sandstones and shales were laid down in estuarine areas. The lignite seams of this formation, together with the occurrence of unios and gasteropods, show fresh-water conditions.

At the close of the Laramie, the relatively quiet conditions prevailing since early Paleozoic time came to an abrupt close. The Castle Mountain area was then raised above the sea, and the sedimentary series were folded in low and gentle undulations that were at once attacked by erosive forces. At this time volcanic activity began at other points on a large scale, furnishing the greater part of the material laid down in the waters that laved the shores of the Rocky Mountain land. The faunal evidence shows estuarine conditions still prevailing along the margin of the newly made land, followed by a recession of the sea and the prevalence of fresh-water conditions. The period of time represented by the Livingston formations must have been a long one, as measured by the erosion of the folded Paleozoic rocks, but in this particular area the record is obscure. During the Livingston period mountain-building progressed, and the cordillera area was fully developed. This orogenic movement was general and continued through the succeeding Eocene period, resulting in the great folds and flexures of the mountain ranges, upon whose flanks the lately deposited Livingston (and early Eocene—i. e., Fort Union) beds were upturned and folded. At this time the volcanic forces breaking through the great thickness of Livingston and Fort Union beds formed the intrusive bosses of the Crazy Mountains, sending out a multitude of dikes and sheets of igneous rock that penetrated the strata in every direction. A few of these reached northward as far as the southern part of the Castle Mountain area. This period was in general, however, one of prolonged erosion, resulting in the carving out of the great intermontane valley between the Belt ranges and the erosion of the Castle folds into a rugged, broken country. These rocks, together with the sediments in which they are intruded, were flexed and upturned by the Eocene crumpling.

At the close of the Eocene, differential uplift ponded back the waters of the Smith River,[1] which had previously flowed eastward down Shields River to the Yellowstone, and formed Smith Lake. At this time volcanic activity began at Castle Mountain. Huge masses of igneous matter were forced upward in the folded rocks, and the diorite boss of Blackhawk and Robinson was formed.

Granitic magmas, forcing their way upward, injected sheets between the more readily split shales and filled fractures in the harder rocks, finally breaking through the anticlinal folds of the western part of the area and forming a great boss or stock. This cuts the folds with so little disturbance that it is evident no great amount of folding can be ascribed to the intrusion itself, though its uprise may have been preceded by an uplifting and fracturing of the beds above it. The intrusion is represented upon the geological cross sections (Pl. IV) as a laccolitic mass intruded in the folded Algonkian shales. This shape and the location of the conduit are purely theoretical, but this theory does not require the replacement of a great block of sedimentary beds, but their simple uplifting. That no absorption of sedimentary rocks took place is clearly evident, as the lack of endomorphic alteration at the contact shows. It seems certain that violent explosive action subsequently took place at this point and a large part of the sedimentary cap was blown off, the adjacent country being thus covered with the fine débris of stratified rocks, mixed with volcanic ash and

[1]Smith River, named in 1845 by Lewis and Clarke for the Secretary of the Interior under Jefferson, is the proper name for what is sometimes called Deep Creek. The latter is so common a name in the West that it has no significance. Indeed, the stage road from Castle to the railroad follows down a "Deep Creek," entering the Missouri near Townsend.



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

PANORAMA OF GRANITE CRAGS WEATHERING INTO CASTLES.

dust. The extent of country covered by this mantle of débris is not known, as it has been largely removed by erosion. It has been found as far north as the low divide between Sheep and Newland creeks in the Little Belt Range, 16 miles north of Castle Mountain. Upon the immediate mountain slopes this material must have been of considerable thickness. Remnants of it 400 feet thick still remain, but these light and readily transported materials were rapidly washed down from the mountain slopes and spurs and carried to Lake Smith, to form the sediments that now fill the valley. Subsequent to this explosive action the eruptions were quieter in character, consisting of great overflows of lava from fissures in the mountain sides. These lava flows streaming down the slopes filled up the hollows and cooled as rhyolite and obsidian.

The last phase of volcanic activity of which there is positive proof is that which resulted in the formation of the two small volcanoes north of the mountain. Of these, Volcano Butte is a most perfect example, its lava flows of basalt filling the valley bottom. The desiccation of the Miocene lake by the downcutting of Smith River followed these volcanic eruptions, since which time erosive forces have been unceasingly at work. A brief episode in the long period of time from later Miocene to the present was the formation of glaciers upon the summit of Castle Mountain, aiding somewhat in the degradation of the region and scattering their bowlder drift over a considerable part of the mountain.

CHAPTER IV.

STRATIFIED ROCKS.

The sedimentary rocks cover the greater part of the Castle Mountain area, as will be seen by reference to the geological map (Pl. III), on which their distribution is indicated. In the region shown by the map the limestones, shales, and sandstones composing the sedimentary series are warped and folded so that the beds are rarely horizontal. Faulting has caused further modification, and the intrusion of the igneous rocks of the old volcano has shattered the beds and produced still further warping and disturbance; sheets and dikes have been injected between the beds or in fissures across them, and have greatly modified the physical character of the rocks themselves.

While the stratified series does not extend to the actual base of the known sedimentary series, it includes a wide variety of sediments representing the vast interval of time from Algonkian to Middle Miocene. Few localities in the northern Rocky Mountains show so wide a range of time represented by fossiliferous rocks.

The stratified rocks are divided into the usual systems, whose fossil forms have been recognizable in this or the adjacent regions. Following the general usage, these systems are subdivided into groups, to which local names are given for a particular geologic province. Thus in this paper the names used for the subdivisions of the various systems are those which have been adopted for the geological maps and reports on this part of Montana and for the Yellowstone National Park. The following table shows these subdivisions:

Table of sedimentary formations of the Castle Mountain mining district.

MIOCENE.
- Smith Lake beds.

CRETACEOUS.
- Livingston group.
- Laramie group.
- Montana group.
  - Fox Hills formation.
  - Pierre formation.
- Colorado group.
  - Niobrara shaly limestones.
  - Benton shales.
- Dakota.
- Kootanie.

	Feet.
JURATRIAS	90
Ellis limestone.	
CARBONIFEROUS	1,800
Quadrant group.	
Madison limestone.	
DEVONIAN	145
Three Forks shales.	
SILURIAN	715
Jefferson limestone.	
CAMBRIAN	2,475
Gallatin limestone.	
Flathead.	
ALGONKIAN	3,000+
Belt group.	

Erosion and corrasion acting upon the diverse rocks of the sedimentary series have produced widely ranging topographic forms characteristic of the rocks themselves, and resulted in strongly contrasted scenery, emphasized by the vegetation, which reflects the various differences of soil. Into large areas of soft shale broad, open valleys are cut, resistant quartzite forms sharp-crested wooded ridges, and the heavy-bedded limestones make bold mountain ridges inclosing the shale valleys, or are cut by streams into deep and narrow gorges.

ALGONKIAN.

The Paleozoic rocks of the Castle Mountain area show two distinct and quite different series. The lowest of these is a group of conformable strata, mainly argillaceous shales or slates, called the Belt formation, from its great development in the ranges of that name. This group, of which a thickness of 8,000 feet or more is known in the mountains adjacent to Castle, is clearly of sedimentary origin, and includes sandstones and argillaceous limestone, but thus far the search for fossil remains has not been successful. We believe it to be of Algonkian age.

Above the Belt group the Paleozoic is of quite different character; the sediments are more modern in appearance, not metamorphosed or altered except locally by igneous rocks, and carry fossils at various horizons.

As is clearly indicated upon the accompanying geological map (Pl. III), these Algonkian rocks cover the greater part of the area represented, and, as will be seen by an examination of the contours, the Belt slates are largely confined to the valleys and footslopes, while the overlying beds of this age define the higher area on the north, and, together with the general mass of Paleozoic limestones, constitute the main mountain mass.

BELT BEDS.

The Belt group has been recognized in the Bridger Range and in the vicinity of the three forks of the Missouri, where it has been provisionally called Algonkian.[1] Both the character of the sediments and their position beneath the beds of Middle Cambrian age indicate their similarity to the Bow River beds of the Canadian geologists, in which Lower Cambrian fossils are found. It has, however, been decided to class the Belt beds as Algonkian.

The strata belonging to the Belt formation, though generally argillaceous in character, include quite pure, dark-colored limestones and beds of sandstone. The shales which form the predominant part of the series and are its most prominent feature are generally gray in color, rather well indurated, and sometimes break into slaty plates, so that they are very generally called slates by the miners. Pl. VI shows the cliffs of this series found in the canyon of Sixteenmile Creek, south of the Castle district, and illustrates the usual character of the exposures of the Belt beds throughout the district.

Within the Castle Mountain area the base of the Belt is not exposed, and the sandstones and conglomerates which compose the lower horizons are not seen. The series presents no definite, well-marked lithological horizons, but there is a general sequence as follows:

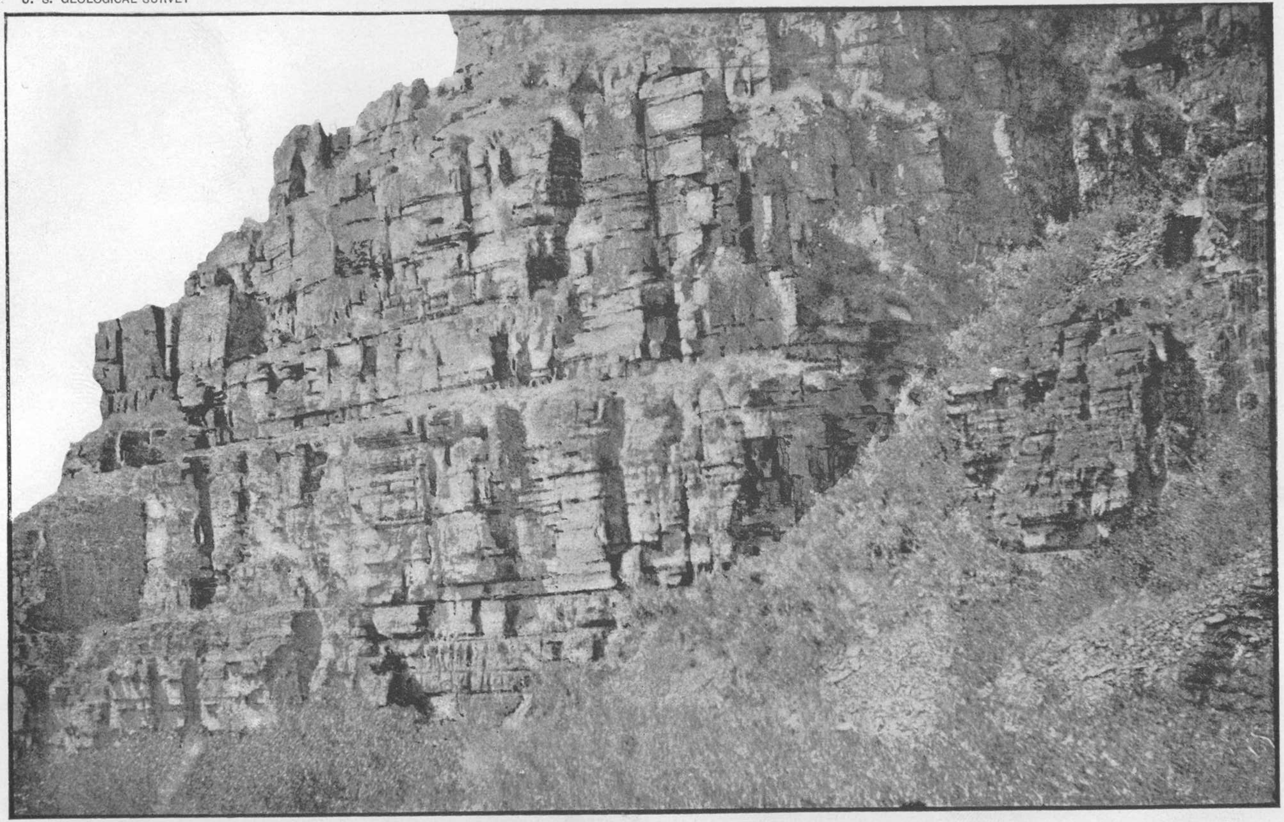
Red shales and slates, forming top of formation.
Sandy shales, with thin beds of ripple-marked sandstone.
Pearl-gray sericitic shales.
Dark-gray, laminated, thin-bedded limestone.
Alternating shales and sandy beds.

The rocks show a slight general metamorphism in their induration and mineralogic nature, and in this respect differ in a marked degree from the shales of the overlying Flathead formation.

The Castle Mountain district, as shown on the geological map, has large areas of Belt rocks. The largest is the broad, shallow valley to the north, lying between Castle Mountain and the Little Belt Range—a valley cut entirely in this formation. The broad valley of Smith River is also eroded in these soft shales, its extension west of Castle Mountain showing Belt beds largely concealed by the silts of the Miocene lake.

The great granite intrusion, which is the leading feature of the geology of Castle Mountain, breaks up through the Belt beds, which about its borders are so much altered as to be scarcely recognizable as the soft, readily eroded beds that compose the formation elsewhere. The conformable relations of the formation to the overlying fossiliferous rocks of the Cambrian are apparent at many localities. Along Willow Creek, however, a fault has brought the Belt shales in contact with the

[1] Geologic Atlas of the United States, folio 1, Livingston, Mont., Washington, D. C., 1894; also Bull. U. S. Geol. Survey No. 110, 1893, pp. 16 and 49.



CLIFFS ON SIXTEENMILE CREEK, SHOWING BELT FORMATION.

Mesozoic strata, and west of Castle Mountain the Smith Lake beds conceal the shales in which the valley has been carved. The area covered by the unaltered rocks of this formation is in strong contrast with that occupied by the more recent rocks. About White Sulphur Springs and on the north slopes of the mountain that fall away to the basin drained by the head waters of the northern branches of the Musselshell and Smith rivers the Belt beds form an open country, with rounded hills and gently modeled slopes, bare of trees and but scantily grassed. The streams cut readily into the shales and fissile limestones of the formation, and the rains wear down the slopes rapidly.

In Castle Mountain the rocks are mostly gray in color, save near the top of the formation, where buff and yellow tones predominate. As already stated, the base of the formation is not shown at Castle Mountain. The limestones form the lowest horizon exposed, and they are seen well developed in the canyon of the Musselshell River, near the mouth of Checkerboard Creek. The overlying, pearl-gray, sericitic shales, whose silvery, silky sheen is so characteristic a feature, occur near White Sulphur Springs and in the valley about Copperopolis. The overlying arenaceous strata in which the thin beds of sandstone weather out as low and rarely conspicuous reefs, whose lines can be seen ribbing the smooth, grassy slopes, can be observed on the northern flank of the mountain and in the low hills west of Volcano Butte. The red shales form a prominent feature along the road from White Sulphur Springs to Castle and Martinsdale, and their relation to the bold reef of Cambrian quartzite is everywhere apparent.

In the mountain proper the Belt beds are extensively altered by contact metamorphism, the rocks being hornstones and related rocks, forming bold exposures with mural faces and masonry-like structure, and breaking into angular blocks with sharp edges, smooth faces, and sonorous ring under the hammer. They have also lost their gray or red color and are darker and often green or purple in tint. Fine exposures occur in all the gorges cut back to the main summit, notably the heads of Fourmile, Willow, Cottonwood, and Warm Spring creeks. The illustration (Pl. VII) shows the walls of Fourmile Creek near the prospects located on the intrusive rocks that cut the altered shales.

The intrusive rocks penetrate the Belt formation very freely, the easy fracture and parting of the rocks lending itself readily to the injection of eruptive masses. For this reason the beds are nowhere seen free from intrusive sheets on the east side of the mountain, but are everywhere intruded and altered and upturned by these rocks. The west side of the mountain, as already stated, is faulted, bringing up much lower beds, and recent intrusions are absent.

On the western flank of the mountain, at the head of Cottonwood and Warm Spring creeks, an intrusive sheet of diabase occurs, the dense, dark, heavy rock resembling iron ore having deceived many prospectors. The heavy pine forest and castellated crags of the granite area are readily distinguished from the areas of altered Belt shale upon the highest slopes of Castle Mountain. The absence of fossils and of definite lithological horizons makes it necessary to map the formation as a whole.

The Belt rocks are splendidly exposed along the course of Deep Creek, on the road from Castle to Townsend, where they form the mountains of the Big Belt Range, west of the area shown on the map.

In general, the copper veins of the region are found in the Belt formation. At Sixteenmile Creek, Copperopolis, and Spring Creek the copper ores are confined to these rocks. The ore bodies of Castle Mountain proper, thus far found in the Belt rocks, are not especially promising, and those which have been seen by us do not warrant development.

CAMBRIAN.

FLATHEAD FORMATION.

The fossiliferous rocks begin with the beds which immediately overlie those just described. These are unlike the latter both in character of sedimentation and in the occurrence of organic remains. That part of the overlying Paleozoic that is of Cambrian age is divisible, on both lithological and paleontological grounds, into two formations, the Flathead and the Gallatin, the former corresponding to the sandstone and shale series and the latter to the limestones. Overlying the series of Belt strata just described there is a bed of quartzite or sandstone which, throughout this region, everywhere defines the base of the fossiliferous rocks. It corresponds to the "basal" quartzite of the early geological reports,[1] which was referred to as Potsdam, and which, in southern Montana and Wyoming, rests directly upon the Archean rocks.

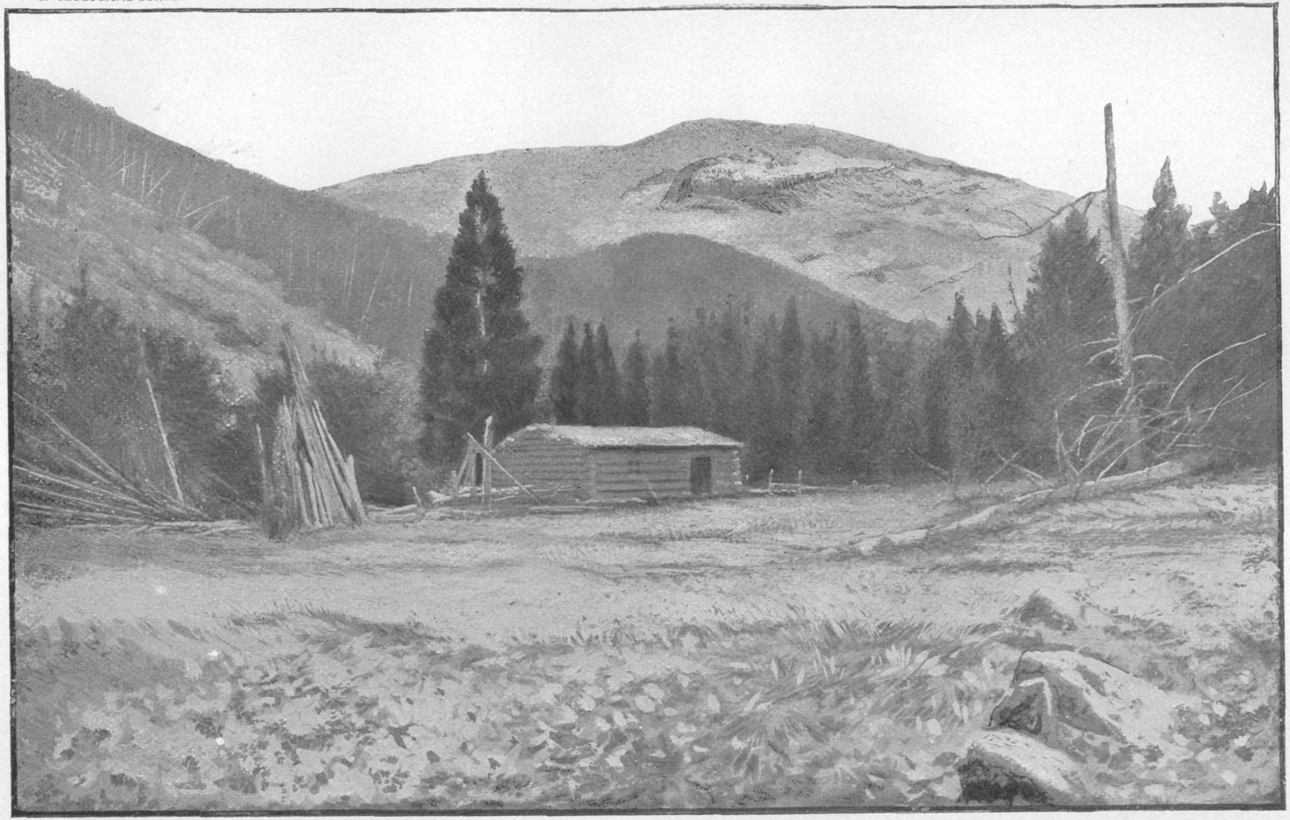
This sandstone, together with the overlying shales and interbedded limestones, constitutes the Flathead formation, which has a total thickness at Castle Mountain of 765 feet, and is characterized by fossils of Middle Cambrian types. The name is adopted from the well-known Flathead Pass across the Bridger Range.

The formation consists of the following members:

	Feet.
Upper Flathead shales	260
Flathead limestones	50
Lower Flathead shales	400
Flathead quartzite	75-100

Flathead quartzite.—The quartzite, the lowest bed of this formation, is the most conspicuous member of the series, and is readily recognizable by its lithological character, its topographic development, and its association with the underlying and overlying shales. The bed is from 50 to 150 feet thick, and varies somewhat in hardness at

[1] Annual Report U. S. Geol. Survey of the Territories, 1872, pp. 16-25.



VALLEY OF UPPER FOURMILE CREEK.

different horizons. The rock is pink or gray in color, usually weathering with a reddish-buff or rusty tint, and consists of firmly cemented, rounded grains of clear quartz and some milky feldspar. No fossils have been discovered in this bed, and it is not ore-bearing. At Castle Mountain this quartzite often forms a conspicuous, wooded reef rising abruptly above the gentle, grassy slopes of Belt shale and separated from the limestone series by a depression cut in the, soft overlying shales. The bed forms a prominent feature of upper Warm Spring Creek, where it may be seen as a bold reef extending down the slope west of the creek and crossing the stream below its upper forks, where it forms a rugged, dark-brown wall On the road from White Sulphur Springs to Blackhawk and Castle this bed is not so conspicuous, but it may be seen close to the road from the Fourmile divide to Blackhawk. Upon the northern flanks of the mountain it is, however, quite well developed, its wooded outcrop everywhere defining the boundary of mountain and valley from the Smith River gorge, northeast of White Sulphur Springs, eastward to Halls, where the ledge crosses the Musselshell and curves about the flanks of the Little Belt Range.

Flathead shales.—These shales are generally laminated, soft-green, purple, or red in color, are frequently micaceous, and they crumble readily. Thin-bedded limestones also occur, and in the middle of the shale belt they are quite well developed. These limestones are dense, gray rocks, carrying trilobite remains, are frequently spotted with green glauconite grains, and have a pitted, uneven surface where in contact with the shale. The beds are seldom more than a few inches thick, but often weather out as low bands showing above the shale slopes. They vary from dense limestones, having trilobites and other fossils on the upper surface of the layers, to conglomerates formed of limestone pebbles, often green or buff, and unlike the gray matrix. These pebbles are generally flat, but occur in the rock without arrangement. Together the limestones form a set of beds, with shale belts above and below, and are hence called Flathead limestones. Frequently layers of limestone oolite occur in which trilobite fragments are found, the rock being gray, mottled with buff, and carrying considerable glauconite. These thin-bedded limestones sometimes weather out in plates or flags of considerable size. The fossils from these limestones are of Middle Cambrian types.

In the western and southern slopes of Castle Mountain these shales and sandstones are rather argillaceous. To the north a second bed of quartzite is found, separated from the basal member by 400 feet of shale. This is seen on the hill back of Copperopolis and in the canyon cut through it by Checkerboard Creek. The section on page 36 gives in detail the character and succession of the Flathead beds of this locality.

Section of Paleozoic strata exposed in gorge of Checkerboard Creek at north base of Castle Mountain.

No.	Cambrian series.	Feet.
26	Limestone; rather massive in outcrop; light-gray with buff tinge and pinkish spots; dense and without crystalline structure	80
25	Limestones, thinly bedded, but with massive outcrop, weathering with rough surface and faint-brown tint; hackly, guttered surface	130
24	Limestone, bluff; dark-gray	25
23	Limestone; dark-chocolate and gray	100
22	Limestone, forming bluff wall; first big cliff ledge of canyon walls; dark-stained and occasional reddish wall of gray limestone	40
21	Limestones; thinly bedded, gray	550
20	Limestones; dark-chocolate colored, dense rocks, weathering gray or white	7
19	Limestones (?); not exposed	25
18	Limestone, forming persistent ledge or cliff; dark-gray and chocolate colored; no conglomerate; carrying trilobite	55
17	Limestone, conglomerate at base and in places, passing into rough weathering, dark-gray limestones above; fauna of this horizon is Cambro-Silurian elsewhere	48
16	Limestone; poorly exposed; splintery, gray rocks	75
15	Limestone; rather thinly bedded; dark-gray, mottled	90
14	Shale with limestone beds of one-half inch to 3 inches in thickness	315
13	Limestone; gray, weathering buff; carrying Cambrian fossils	28
12	Shale; thinly laminated, crumbly, purple-gray	30
11	Limestone	1
10	Shale; gray, crumbly	4
9	Limestone; thinly bedded, dark-gray, mottled with buff	10
8	Shale in one-half inch layers, carrying interbedded layers of fissile, impure sandstones and limestones	200
7	Shale; gray and purple, thinly laminated	60
6	Sandstone; stained black with organic material	1
5	Shale; dark-green, crumbly	5
4	Quartzite; resembling that at base of section	25
3	Limestone; thinly bedded, gray limestone, weathering buff, and carrying fossils	20
2	Shales; thinly laminated, crumbly, micaceous, green and gray, red and purple; not well exposed	400
1	Quartzite; dark-red, buff, or gray; conglomerate at base	150
......	Belt shales	....

This section differs from sections of the Cambrian farther south in having a much greater development of the Flathead shales, which, with the interbedded limestones, have here a total thickness of 945 feet. The overlying limestones do not show the lithological differences seen at other localities, and as a systematic search for fossils was not made, the horizons of this part of the section are only tentative. The dip is westward and varies from 45° for the quartzite, the lowest bed exposed, to 25° for the heavily bedded, light-colored Carboniferous limestones that form the upper end of the gorge. In topographic relief the Flathead shales form a ravine or grassy interval between the wooded quartzite area, and the rugged limestone outcrops above. Exposures are rare and must be sought along the banks of the streams or steep divides, as they readily weather and disintegrate into fertile soils, which favor vegetation and effectively conceal the beds.

GALLATIN LIMESTONES.

The upper part of the Cambrian beds, consisting mainly of quite pure limestones and characterized by fossils of an Upper Cambrian type, constitute the Gallatin formation, the rocks being typically developed in the Gallatin Range. The lowest bed is a rather massive, heavy-bedded limestone, which has generally a chocolate color mottled with yellow or buff. This bed often forms a bold bluff wall, rising abruptly above the slopes formed by the more readily weathered beds beneath.

This limestone bed is succeeded by a thin belt of shales, barren of fossils and seldom exposed, overlain by rather thinly bedded limestones and conglomerate. These limestones, which are generally pebbly, constitute an important horizon. Beds of limestone 4 to 6 inches thick alternate with more crumbly, argillaceous beds 3 to 5 inches thick. The fossils are Upper Cambrian species, but include many that pass into Silurian rocks, and it is questionable whether these beds do not belong to that period. These conglomerates are not distinctive of the Gallatin, however, as those found in the underlying Flathead formation are very similar in appearance.

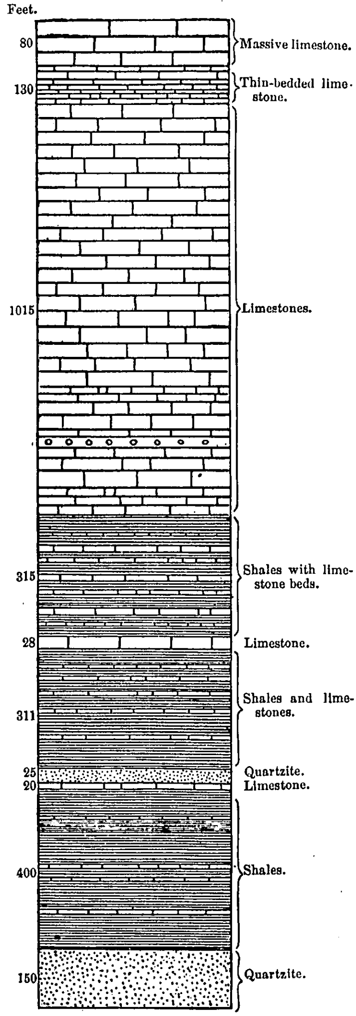


FIG. 5.—Columnar section of Paleozoic beds seen in canyon of Checkerboard Creek.

Fossils: *Crepicephalus* (*Loganellus*) *montanensis* Whitf., and *Arionellus tripunctatus* Whitf., from beds in valley near wagon road, west side of Castle Mountain.

SILURIAN.

JEFFERSON FORMATION.

The limestones which farther south are classed as Silurian and form a prominent part of the Paleozoic series near the Jefferson River are recognizable at Castle Mountain only by their lithological character and their stratigraphic position.

The rocks are all limestones, generally massively bedded and gray in color at the base, grading above into dark-brown and blue-black saccharoidal limestones with fetid odor and a considerable proportion of arenaceous material. These beds are often characterized by an abundance of small calcite geodes, and rarely carry indistinct remains of corals. The formation is distinguished with difficulty from the limestones above and below, forming with them the great limestone series that collectively make the mountain-building rocks of the region. The black limestones occur on the northwest side of the mountain at the Grasshopper mine, where they show considerable endomorphic alteration, due to the proximity of the granite. They are also seen on the divide above the Cumberland mine in the rock cut beside the road from Robinson to Castle.

A splintery, dark-gray limestone, having a thickness of 550 feet, overlain by 165 feet of chocolate and dark colored fetid limestones, is, in the absence of any paleontological evidence, assigned to this horizon.

DEVONIAN.

THREE FORKS SHALES.

The series of shales and thinly bedded limestones which carries a well-marked Devonian fauna at the Three Forks of the Missouri is not readily recognizable in the Castle Mountain area, as the beds are fissile limestones not easily separable from the overlying Carboniferous, and no fossil remains have been obtained. Its presence to the north and south, however, makes it probable that beds of this age are included in the great series of Paleozoic limestones.

A total thickness of 145 feet is assigned to this period in the section in Checkerboard Canyon. The rocks are thinly bedded, though together they form massive exposures. They are generally gray, mottled or blotched with pink or buff, and often weather with marked red color. There is an abrupt change in the character of the beds at the base of the Carboniferous, so that the line of separation is made in the field more readily than it can be described.

Exposures may be found in Checkerboard Canyon, of which a section has been already given, and along the northern and southwestern flanks of the mountain. Near the Cumberland mine and at Robinson and Blackhawk contact metamorphism, produced by the large bodies of intruded igneous rock, obscures the normal character of the limestones so that they can not be distinguished from the other Paleozoic strata.

CARBONIFEROUS.

The beds of this age form the most prominent part of the great series of mountain limestones. As will be seen from the geological map, they cover a considerable portion of the Castle Mountain area, and to them is due some of its boldest and most picturesque scenery. They are, moreover, important from an economic standpoint, as they appear to be peculiarly fitted for ore carriers, and in them have been found most of the important ore bodies.

The beds of this epoch are chiefly limestone, thinly bedded, and dark in color at the base, and massive and white above. This series is overlain by shaly and arenaceous beds, with interbedded massive limestones characterized by Lower Carboniferous fossils.

In the field the rocks are naturally divisible into three series, but the fossil remains are all of Lower Carboniferous types and the fauna of the Coal Measures of the eastern United States has not been found. But two divisions are therefore made; the limestones are grouped together as the Madison limestones, this terrane being well developed along the river of that name, while the overlying earthy and sandy series is the equivalent of the Quadrant formation of the Yellowstone Park. The two divisions have an aggregate thickness of 1,800 feet, distributed as follows:

	Feet.
Quadrant formation	600
Madison formation:	
Massive limestone	400
Thin-bedded limestone	800

The Madison limestones in this region are the most prominent part of the Paleozoic series. The sharp folds into which they have been compressed have been largely uncovered, and the ledges stand up white and glaring above the gentle slopes formed by the overlying beds. They are essentially the mountain limestones, and generally in this part of the Rocky Mountains sharply define the mountains from the plains or valleys of soft Cretaceous rocks. This peculiarity is seen at Castle Mountain in the anticlinal fold that forms its eastern part, and to the southwest of Castle, where the abrupt transition from gentle Cretaceous slopes to limestone plateaus is most striking. The upper strata being massive and heavily bedded, this transition is more strongly marked than if they were of the lower thinly bedded limestone. Upon the western slopes of the mountain, as on the eastern, the heavy beds of limestone form a line of white scalloping outcrops resting upon the mountain flanks.

MADISON FORMATION.

Flaggy limestones.—Immediately overlying the yellowish shaly limestone forming the top of the series referred to the Devonian there is a series of rather dark-colored, compact, fine-grained limestone, splitting readily along the bedding planes into slabs or flags. The total thickness of these thinly bedded limestones included between the Devonian and the base of the massive limestone is 800 feet. Throughout this thickness there is a considerable variety in color, from dark-gray or blue-gray to brown and buff, and from compact amorphous limestones to those that are coarsely crystalline. The rocks frequently carry chert, but it is irregularly distributed, of varying color, and forms angular masses.

Fossils occur in the lowest beds of this series and are abundant throughout. The most noticeable feature is the great abundance of crinoid disks which appear in the lowest layer. In the Devonian rocks they are small, scarce, and inconspicuous; here the rock is largely composed of them. Neither fossils nor lithologic differences offer any grounds for dividing these beds into different horizons.

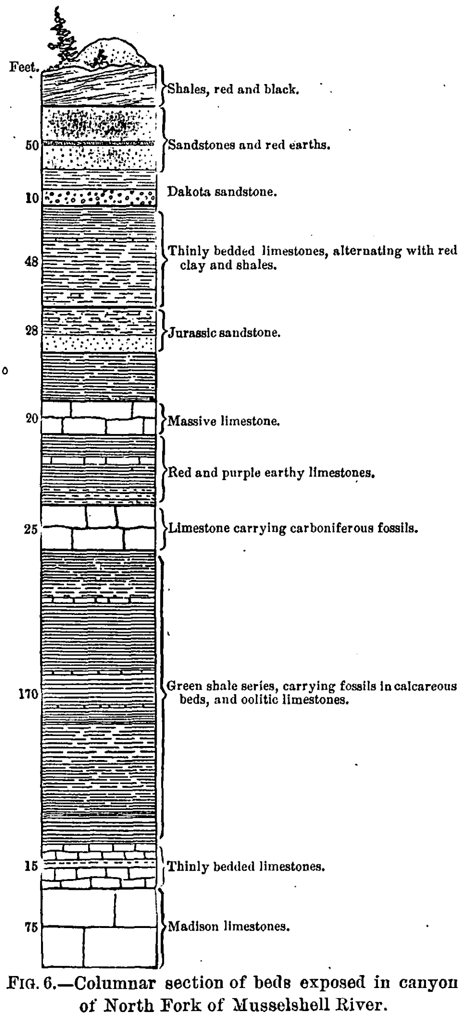


FIG. 6.—Columnar section of beds exposed in canyon of North Fork of Musselshell River.

Massive limestone.—Above the series of thinly bedded limestones just described there is a thickness of 400 feet of white, massive limestone. The rock is always light-colored, generally dense, but sometimes crystalline, with irregularly distributed chert rarely forming layers through it. As a whole it is readily distinguished from the darker, thinly bedded limestone beneath, both from the character of the rock and the great difference in weathering. The beds are thick and division planes seldom noticeable, the rough, cavernous, irregular weathering and uneven fracture being quite constant characters. Where cut through by streams it forms narrow gorges with precipitous walls showing cavernous recesses. It frequently holds caves, and abandoned waterways are not uncommon. Where the streams penetrate it to the softer rocks it forms the gateways, so common in this mountain region, from the upper valley or gorges to the open lowland.

The rocks may be seen well exposed at many localities. The ore body of the Cumberland mine lies in this bed, and the slopes about the mine show good exposures, though the rock is slightly metamorphosed. The gorge of Warm Spring Creek and the adjacent mountain benches show this horizon where it has been somewhat carefully prospected.

When sharply folded the limestone is often brecciated along incipient fault lines and in such places is often colored by iron. This has led many prospectors to look for minerals at such places.

The road from White Sulphur to Castle passes up the gorge of Fourmile Creek, cut in Carboniferous rocks, this horizon being prominent, and it is also seen where the various forks of Flagstaff Creek cut their way to join the Musselshell. It is a most important element in the scenery of the region and a key to the position of the adjacent beds and to the geological structure.

QUADRANT FORMATION.

This consists of a variable series of sandstones and shales, with pure and impure limestones, that overlies the great limestone series of the region. In the southern part of the State the formation consists of quite pure white sandstones with occasional intercalated limestones, but argillaceous materials appear farther to the northward, and at Castle Mountain form an essential part of the formation. A characteristic feature is the occurrence of impure earthy beds of bright-red color immediately above the massive limestones last described. Higher in the series beds of bright-green shale, usually alternating with sandstones or impure limestones, form a conspicuous and readily recognizable horizon.

The total thickness of the formation averages 600 feet, the upper limit being the granular, buff, or pink sandstone of the Juratrias. The following section illustrates the character of the beds. It is taken at the beginning of the Musselshell Canyon, at the northeast base of the mountain.

Section of Carboniferous and Juratrias beds exposed at east end of Musselshell Canyon.

	Feet.
Mesozoic:	
Black shales	500
Red earths	......
Sandstone, buff-colored, granular and crumbly	20
Red sandstone	5
Sandstone, indurated and tough, gray to buff	10
Sandstone, a shaly gray rock	5
Interval	10
Sandstone, supposed Dakota, gray at base	10
No exposure	20
Limestone, light-brown, rusty colored	2
Not exposed	30
Shaly sandstone, a soft light-gray rock, weathering down readily and probably passing into impure limestone, with red, nodular streakings.	12
Sandstone, shaly at top, soft-red to buff, and massive at base. Probably represents base of Juratrias	28
Paleozoic:	
Interval	30
Massive limestone, gray, blotched with pink, crystalline and granular, resembles sandstone	15–20
Interval, showing red, shaly earths	15

Paleozoic—Continued.	Feet.
Limestone, gray massive bed	5
Red earths, magnesian or impure limestone; red clays with limestone balls.	8
Limestone, dense, pure, gray, structureless	3
Purple magnesian limestone, weathering to red earths holding nodular limy masses a few inches in diameter	15
Limestone bed, upper part gray in color and quite massive, with abundant crinoid stems and Lower Carboniferous fossils. Lower 10 feet thinly bedded (1 to 2 feet) and red stained	25
Black shale, not well exposed	20
Limestone, dense and massive, not platy	5
Shale, dark-colored	3
Limestone, carrying fossil remains	1
Shale, black	1½
Limestone, carrying brachiopods and other Carboniferous fossils	½
Shale, reddish at base	27
Shale, probably green, poorly exposed	15
Limestone, dense, dove-colored, platy fracturing, without crystalline structure or fossils	1
Shale, bright-green	20
Limestone, impure, green	1
Shale, gray	10
Shale, green	18
Shale, weathering to black or blue-black clays	15
Limestone, a dense, platy, buff-colored, splintery fracturing, oolitic rock.	1
Shale, dark-green, weathering to black or rusty colored earths	8
Shale, light-green, tinged with purple at top, where it passes into a darker shale above	5
Shale, light-green, neither soft nor laminated, carries Fenestella and crinoid stems, etc	3
Earthy bed, limy and argillaceous, weathers to red clay with green, limy masses in it	15
Limestone, dense, finely crystalline, crackled	5
Limestone, impure and shaly, gray, weathering buff	5
Limestone, oolitic, platy	5
Limestone, gray, fissile and splintery, dove-colored to light-gray	15

This section shows clearly the variable nature of the deposits of the closing part of Carboniferous time. The limestones associated with the green shales are frequently oolitic in character, and like the thick beds higher in the series carry typical Lower Carboniferous fossils.

The green shales form a marked persistent horizon throughout the Castle Mountain area, rarely showing exposures, but weathering as gray earth. These green shales are exposed just below the Cumberland mine above Castle, where a cutting for a new road has left an excellent exposure. They are also seen on the hills east of White Sulphur Springs, and on the slopes west of the Grasshopper mine. At this latter place a section shows essentially the same sequence and thickness as that at Musselshell Canyon. Above Checkerboard Canyon, back of Copperopolis, these shales and the associated beds are well exposed, and their relation to the limestones is clearly seen. Another excellent exposure is found in the canyon of Flagstaff Creek, where that stream cuts through the Flagstaff anticline.

Just above the Fourmile Canyon, through which the Castle road is built, the bright-green shales are exposed on the slopes and have been laid bare in prospecting. They are cut here by the big dike elsewhere mentioned.

The limestone which forms the top of the Quadrant formation is a massive bed weathering as a rough white ledge, and carrying abundant Carboniferous fossils. It is quite like parts of the massive limestone of the Madison.

JURATRIAS.

The Ellis limestones take their name from the old military post of Fort Ellis, about 50 miles southwest of Castle Mountain, and are prominently developed in the mountain of that name. In the Castle Mountain district they are distinguished with difficulty, and must be sought with care. Their position beneath the Dakota quartzite and above the massive white limestone that caps the Quadrant formation defines their limits, but fossils are not always found.

The beds assigned to this age include a sandstone, usually granular, buff in color, but weathering red or pink, overlain by a dense white limestone resembling that immediately beneath it, but carrying Jurassic fossils. This passes into a sandstone above, and is capped by red earthy shales. The beds included between the fossiliferous Carboniferous and the quartzite—assumed to be the base of the Cretaceous—are 90 feet. There is a total absence of the drab-colored argillaceous limestones which form the bulk of the formation farther south, and which contain an abundance of fossils, yet the period is represented by the purer limestone that here carries the same species found in the argillaceous beds.

Exposures were recognized in the canyon of Flagstaff Creek, and the following fossils, identified by Mr. Stanton, were collected:

Ostrea sp.
Camptonectes extenuatus M. and H.
Gervillia montanensis Meek.
Astarte packardi White.
Trigonia montanensis Meek.
Pinna kingi Meek.
Pholodomya kingi Meek.

In the section made at the mouth of the Musselshell Canyon no fossils were found, but the stratigraphic succession is the same.

The Triassic period, if represented at all, forms the sandstone at the base of the Ellis. The extensive Red Beds of Wyoming have, so far as we have observed, no development in Montana, and beds simulating them are Carboniferous in age, as indicated in discussing the Quadrant formation.

The Ellis is usually defined by an upper sandstone separated from the Cretaceous sandstone (or conglomerate) above by red shales and fissile sandy beds.

The abrupt change from Carboniferous to Juratrias is seen in exposures a few miles east of this section at Musselshell Canyon, where a dense pinkish-gray limestone full of Lower Carboniferous fossils is succeeded by a sandstone with a foot or two of conglomerate at the base, the pebbles being of chert and limestone. Both the conglomerate and the sandstone into which it grades carry abundant Jurassic fossils, mainly *Ostrea glabra*.

CRETACEOUS.

KOOTANIE.

The strata whose outcrops have been included with the other Cretaceous terranes, and which are shown by one color upon the accompanying geologic map (Pl. III), certainly include at the base a series of sandstone and shales equivalent to the Great Falls beds farther north, known to be of Kootanie age. Although there is no definite paleontologic evidence establishing the existence of the Dakota group in Montana, the series of beds lying above the fossiliferous beds of Jurassic age and beneath the black shales of the Benton formation have been heretofore provisionally called Dakota, and so mapped. The characteristic conglomerate which in the southern part of the State occurs near the base of the series of beds thus delimited corresponds in lithologic character and habit with the beds in Colorado described as Dakota, but this is rather weak evidence on which to correlate a formation. In the neighborhood of the Great Falls of the Missouri, where the Jurassic has been recognized[1] and the Benton reaches its typical development, the interval between the two formations includes a thickness of several hundred feet of arenaceous and argillaceous sediments, together with an important coal seam. Fossil plant remains gathered from these intervening beds are of Kootanie or Lower Cretaceous types. No unconformity is recognizable between this and the Benton shales (fossiliferous), but sediments of similar character extend to the top of the series. The only paleontologic evidence consists of fresh-water shells, which alone furnish no evidence for discrimination. It is thus fairly open to question whether the rocks called Dakota in this region are really of that age.

In the Castle Mountain area the Kootanie is believed to be present; at least the coal seam mined at Checkerboard Creek, together with the adjacent beds, is believed to be the equivalent of that found along the flanks of the Little Belt Range farther north. The overlying beds resemble in character those generally described as Dakota in the northern Rocky Mountain region. The beds supposed to be of Kootanie age consist of thinly bedded sandstones and red earthy shales, with a coal seam near the top, beneath a heavy quartzite bed that later is arbitrarily assumed as the base of the Dakota. The total thickness of these beds does not exceed 300 feet.

[1] W. H. Weed, Two Montana coal fields: Bull. Geol. Soc. America, Vol. III, p. 309.

DAKOTA.

The overlying strata, supposed to represent the Dakota, consist of a heavy sandstone bed at the base, overlain by varying succession of shaly sandstones and earthy shales. The section given in fig. 6 shows the sequence and thickness of the beds at the mouth of the Musselshell Canyon.

The basal bed is generally sandstone, often a conglomerate at the base, the pebbles being of black and white chert or quartzite. The sandstone is often indurated to a quartzite, is gray in color, but weathers with a rusty ferruginous crust. It breaks generally into massive blocks, and by its resistance to weathering occupies conspicuous positions wherever it occurs. Its outcrops are generally covered by a growth of pines. The relation of this bed to the fossiliferous Jura is well seen in the synclinal trough east of Blackhawk. A similar relation is seen in the canyon of Flagstaff Creek. The quartzite, which is so readily recognizable, may be used as a ready reference plane, defining the Carboniferous from the shaly Cretaceous beds in which prospecting for ore deposits is useless. Above Checkerboard Canyon the coal seam lies just beneath the quartzite, and in prospecting for a further extension of the seam, that is the bed to follow. Near Castle this bed is conglomeratic, and is well exposed on the hillsides above the town. Its distribution is shown upon the map, and it is so general along the outer margins of the limestone area as to make a mention of specific localities unnecessary. No fossils have been found in the quartzite, but the red clays above it have yielded fragmentary fossil remains from the faulted area southeast of Elk Peak, near the quarry where the sandstone is taken out for building purposes for use at White Sulphur Springs. These fossils have been examined by Mr. T. W. Stanton, who reports that they are fragments of a unio and of a bone, possibly of a turtle.

A peculiar feature of the series of beds included under the name Dakota is the presence of a bed of dense lilac or purple rock, which closely resembles in field appearance a dense volcanic rock. Under the microscope this is seen to be a volcanic ash, thus proving the occurrence of volcanic activity during the Dakotan epoch. This is in perfect accord with the observations of Dr. Dawson upon the Kootanie and Dakota rocks of Crows Nest Pass in the Canadian Rocky Mountains. This purple bed is a persistent horizon throughout the district and has been recognized by one of the writers throughout the region as far south of Castle Mountain as the Teton Range of Wyoming.

COLORADO GROUP.

Within the Castle Mountain area the distinction between the Colorado and Montana groups of the Cretaceous system is an arbitrary one, as no satisfactory paleontologic evidence has been procured upon which to base a division of the groups.

The two divisions of the Colorado—the Benton and Niobrara formations—are not distinguished on the map, the line of division being too indefinite to permit separation.

Benton formation.—This is a series of black carbonaceous shales, with occasional thin beds of sandstone and arenaceous shales. It is essentially an argillaceous formation, whose dark-gray or black color permits its ready distinction from the beds below. Concretionary clay ironstones occurring in the black shales frequently carry fossils, the shales being generally barren. The sandstones are usually impure and argillaceous and occur most prominently in the upper part of the Benton.

Good exposures occur on the east side of Warm Spring Creek below the road crossing. The black shale is here fossiliferous, the following species identified by Mr. T. W. Stanton having been collected: *Inoceramus umbonatus*, M. & H.; *Baculites asper*, Morton.

Niobrara formation.—This formation constitutes the upper part of the Colorado group, and consists in this region of rather lighter colored, gray, arenaceous shales and impure sandstones, passing gradually into the black shales beneath and differing from the lead-color and gray clays of the Pierre above. The sandy shales, when sharply upturned, frequently weather out in irregular reefs projecting a few inches above the slopes of gray shale and resembling long lines of tombstones.

The upper limit of the Niobrara is assumed to be the conglomerate, formed of black and white quartz pebbles, that is a readily distinguishable horizon in the vicinity of Castle Mountain.

In the valley of Alibaugh Creek, a few miles west of the town of Castle, the Colorado shales are highly indurated and metamorphosed—the result of the intrusion of the granite core by which the shales are here abruptly cut. The process of alteration has been so complete that the formation has lost all its ordinary characteristics, and here closely resembles the similarly altered Algonkian beds so commonly found upon the flanks of the granite massif. The rocks consist of dense, flinty hornstones and vitreous quartzite, and light-colored, porcellanous, adinole-like rocks. The original bedding is only recognizable upon careful examination, the rocks being jointed and breaking readily into small cubical or angular pieces.

The total thickness of the group is estimated at 2,200 feet. Good exposures are rather uncommon, though the formations cover extensive areas of the Castle Mountain region. The town of Castle is built upon these and the overlying shales of the Montana group, and good exposures are seen in the bluffs of Warm Spring Creek below the road. Bonanza Creek has cut a narrow valley through them on its way to the broad open country of Coyote Basin, and the black shales are seen in the synclinal trough east of Willow Creek near White Sulphur Springs.

The sections of the beds exposed at the south base of Castle Mountain given on subsequent pages, show the character of the Colorado group as developed in this region.

MONTANA GROUP.

This embraces the two formations, Pierre shales and Fox Hills sandstones, which are not readily distinguishable at this locality, and are indicated by one color upon the map.

Pierre shales.—This formation consists chiefly of a thickness of 2,000 feet of leaden-gray clays or clay shales, carrying rounded, limy concretions, and having occasional thin beds of sandstone in the series. These shales form a very sticky soil, becoming dry and cracked during the summer and weathering into clays that most effectively conceal the beds themselves. No definite line between this and the overlying Fox Hills can be drawn in this region, as the beds become more and more arenaceous and grade into the sandy shales of the latter.

Fox Hills sandstones.—This formation consists in this region of a body of gray sandy shales of varying texture and appearance, passing into a buff-colored sandstone at the top.

Exposures of the Montana group occur upon the southern and eastern sides of Castle Mountain, but the actual outcrops are rarely seen. A section made along the ridge between Alibaugh Creek and the town of Castle is given herewith. The section already noted gives the sequence and thickness of the beds as far as known. Along the course of lower Warm Spring Creek and in the hills south of the road about Woodman Creek the beds may be seen fairly exposed.

Section near the town of Castle.

	Feet.
Alternating shales, sandstones, and arenaceous beds belonging to the Benton formation	1,000
Quartzite, varying to sandstone, forming prominent outcrop and probably of Dakota age	20
Sandy shales, breaking into fine débris and seldom exposed	110
Sandy shales, carrying indurated sandstone layers near the base. The series is stained black with carbonaceous material and resembles the Dakota shales of the Yellowstone Park section	300
Hard, dense, black limestone, weathering dark-gray. The rock is tough, carries chert, and is not crystalline	20
Impure sandy shales	10
Quartzite, the central part of the bed being somewhat shaly	36
Impure argillaceous limestones	110
Intruded sheet of porphyry	12
Limestone, dense but not crystalline, gray in color, and breaking readily into fine débris	100
Olive-colored, dense sandstone	10
Light-colored limestone, breaking readily into fine débris. Upon fresh fracture the rock appears of granular texture and of dark-gray color, carrying streakings of lighter material	90
Dark-gray limestone, carrying shell remains which appear to be Carboniferous	40
White limestone, much decomposed, but well exposed in prospect pit	10
Lead-colored limestones, cut by transversely trending dike	25

	Feet.
Shaly beds, which are baked and hardened, resembling impure limestones	105
Intruded sheet of porphyry	25
Dark-purple and brown shales, which are much baked and form dense and hard hornstones	20
Intruded sheet of porphyry	15
Metamorphosed black shales	15
Altered green shales and calcareous beds	25
Flaggy limestone, much decomposed and having porous, spongy layers, but no fossils	5
Débris of light-colored limestone	30
Chert-bearing, dove-colored, dense limestone	2
Altered shales and intercalated limestones	60
Limestone bed forming ledge, and exposed white line crossing slope	7
Altered limestones or shale, white, dense in structure and not crystalline, with some flinty, baked shale that is black and resembles the Algonkian	75
Intruded porphyry sheet	15
Green Carboniferous shales, which are baked to a gray, splintery limestone-like rock	125
Limestone, much altered, breaking into small angular fragments. In structure the rock is finely saccharoidal, often brecciated, much decomposed, and varies from a pink to a gray color	50
Leaden-gray spotted limestone	3
Intruded porphyry sheet	6
Limestone, brown-gray in color, thinly bedded, and evidently not belonging to the massive series of Carboniferous limestone. These beds extend to the contact with the granite stock. The contact is marked by considerable alteration, the granite being the usual fine-grained porphyritic forms, with a zone not over 50 feet wide of rotted, decomposed rock, showing baked crystalline limestone and porphyry decomposed to a light-yellow rock, quite different from the adjacent altered limestones, which are brown-gray, and not perceptibly whitened by contact metamorphism, although finely granular in structure	150

THE LARAMIE.

This formation, which is so generally coal-bearing along the front of the Rocky Mountains, is not well exposed in the Castle Mountain area. It is essentially a series of light-colored arenaceous beds, in strong contrast with the dark-colored argillaceous shales beneath and the somber-colored beds of the Livingston above.

The strata consist of massive light-colored sandstones with intercalations of gray shale and seams of coal. The rocks are well cemented, and the sandstones formed of well-rounded grains of quartz with little feldspar and mica No fossils have been collected from these beds at Castle Mountain. Good exposures occur at the mouth of Warm Spring Creek, where the beds are sharply upturned, and the ledges can be traced along the slopes to the south, outlining a minor anticlinal fold into which the sediments have been flexed. A few openings have been made on the coal seams in this vicinity and show the best fuels yet discovered near the mines. The seam at the forks of the creek overlies 250 feet of gray Laramie sandstone, and is overlain by about the same thickness of similar rocks. The strata are vertical at this place.

Exposures of the Laramie also occur east of Robinson Creek, a couple of miles below Castle. The total thickness probably averages 500 feet. The formation is readily located by its relation to the brown beds of the Livingston formation.

Near Castle the ridge of volcanic rock south of the schoolhouse marks the base of the Livingston formation.

LIVINGSTON FORMATION.

Upon the south and southeast sides of Castle Mountain there is a great thickness of dark-colored sandstones, grits, and conglomerates, with interbedded shales, constituting the Livingston formation.[1] The rocks of this age, together with a higher series, form the great mass of the Crazy Mountains, and the wide valley between that group and the Bridger range and Sixteenmile mountains is cut in these strata.

The beds constituting the formation are generally dark-colored, of various shades of brown or rarely green. They are usually coarse sandstones, composed almost wholly of andesitic volcanic material that shows rapid deposition and but little sorting by water. About 200 feet above the base of the series occurs a light-colored bed that is a pure white sandstone, presenting a strong contrast to the adjacent ledges. This is a horizon by which it is possible to trace out the intricate folding that prevails along the course of the South Musselshell. The beds are very generally intruded by sheets of igneous rock of Crazy Mountain types, whose upturned edges weather as bold combs, rising above the slopes formed of Livingston rocks.

An excellent section of these rocks, and one showing their foldings conformable with the underlying Mesozoic series, is seen where the road from Livingston and Bozeman crosses the divide between South Musselshell and Smith rivers.

Section of beds exposed at head of Smith River.

	Feet.
Brown sandstone or tuff bed, well indurated and breaking into small, angular fragments of one-fourth to three-fourths inch across. This ledge forms foot-slope ridges and buttresses rising abruptly from the walls of the valley south of Castle Mountain..	25
Fine-grained tuffaceous strata, often brown and carrying lignitic shale, but inconstant in character and variable horizontally...	105
Light-gray sandstone formed of the sorted grains of volcanic material; dips eastward at 45°. This bed forms the valley rim.	25
Tuffaceous sandstone with concentric, spherical, shelly weathering	5
Tuffaceous sandstone, brown in color and varying to green. Generally crumbly and carrying round concretions of all sizes, up to 2 feet, which resemble cannon balls..................	40

[1] W. H. Weed, Laramie and overlying Livingston formation: Bull. U. S. Geol. Survey No. 105.

	Feet.
Fine-grained tuffaceous sandstone, green or grayish-green in color, crumbling readily to a dicy, shelly débris and carrying occasional spherical concretions from 2 to 3 feet in diameter	15
Fine-grained, shaly, tuffaceous sandstone	36
Tuffaceous beds, generally concealed by other débris	353
Conglomerate composed largely of pebbles of volcanic material	5
Soft tuffaceous sandstone	90
Dark-green and rusty-brown tuffaceous beds, varying considerably in texture and coarseness of composition. The beds change rapidly in character horizontally	35
Green, fine-grained tuffaceous sandstone, crumbling readily to a coarse, sandy débris and much resembling the tuffaceous beds of the fossil forests in Yellowstone Park	5
Fine-grained greenish sandstone, weathering brown	7
Limestone; gray on fresh fracture and weathering with a seal-brown surface	2
Umber-colored tuffaceous beds. The series thus far given is of the general brown or umber tint, and differs in this respect from the underlying beds, which are generally green in color	10
Granular sandstone, breaking readily into green, splintery débris, whose fracture is at right angles to bedding, forming small angular bits an inch in diameter	5
Bed of gritty sandstone of a bluish-green color	3
Black tuffaceous shale, breaking into fine, angular débris	15
Limestone bed	½
Greenish-gray sandstone, weathering into roundish ledges, but breaking into angular bits. This rock is unlike a true volcanic breccia and quite distinct in character from the Laramie beds	10
Fine-grained tuffaceous beds formed of volcanic material and weathering readily, so that exposures are seldom seen. These rocks form the small inclosed valley at the head of the stream	300
Light-brown, fine-grained, steel-gray sandstone, dipping south at 60°. The rock weathers in smooth, round forms and is a very dense sandstone resembling limestone in appearance	6
Sandstone; light-gray in color; composed of angular bits of material that are not markedly volcanic. It is separated from a ledge above by 2 feet of shale	5
Fine-grained, buff-brown, tuffaceous beds, seldom well exposed, but showing crumbly, black pieces, forming a sandy débris covering the exposures	250
Very fine-grained, tuffaceous rocks, olive-green in color	10
Shaly beds, crumbling readily to fine, sandy débris and black earth	125
Conglomerate and volcanic breccia; contains well-rounded pebbles up to 6 inches in diameter, and also a well-cemented, angular breccia and grit. The ledge dips south at 60° and forms a very rough and jagged comb that stands out above the gentler slopes. The upper part of this bed may be classed as a true volcanic breccia, as it carries angular bits of andesite up to an inch in diameter, scattered through a cementing material of fine-grained tuff	100
Soft, readily weathering, tuffaceous beds of an earthy-brown color.	200
Sandstones, white in color and forming long lines of tombstone-like flags, rising above the grassy slopes	10
Dark, rusty-brown and black shale, seldom exposed	300

	Feet.
Sandstone, resembling volcanic grits, but fine-grained and of doubtful character	50
Shale, light-brown in color and weathering readily to soft, earthy débris	20
Brown shale, not well exposed	135
Sandstone, gray, composed of the sorted grains of quartzose and feldspathic material, rock being of Laramie type	5
Shales; soft, shaly beds seldom showing their character either in débris or in soil, and not exposed in this section. No traces of coal were seen, although this must be Laramie	1,950
Olive-green sandstone, dipping 55° south	5
Impure sandstone, breaking into laminæ one-half inch thick and showing fucoid markings	45
Shales; weathered down and showing dark-colored, clayey débris	280
Gritty sandstone that becomes a conglomerate in places. It resembles the Dakota, but is finer grained, and the quartzite pebbles are of many varieties	5
Shales, which are not exposed	220
Sandstone, well indurated, hard, yellowish on fresh fracture and weathering gray. Forms very massive outcrop on mountain slope, where it breaks into flags whose lines extend along the slope. The rock is formed of well-sorted and fine-grained granitic material	20
Shaly beds and sandstones, not exposed	55
Sandstone that is somewhat calcareous; contains impressions of fossils; dip, 65°	8
Interval in which beds are not exposed	120
Sandstone, hard and vitreous, passing into quartzite; dip, 53°	15
Shales, not well exposed except near the underlying beds, where the rocks are gray and argillaceous	112
Sandstone, fine-grained, well-bedded, dense, and of a brownish-gray color	5
Shales and impure limestones and sandstone beds, whose character is seen in the gopher heapings upon the slope	430
Black shale, very soft, laminated, weathering to soft, black earths. The slope formed by this shale is strewn with blocks of quartzite from some higher ledge	200
Red earths, formed by the weathering down of beds not exposed.	210
No exposure	165
Sandstone, gray, and breaking into flaggy masses	6
Red earths	12
Sandstone, quite massive, dipping at 65°; probably the source of the quartzite blocks seen below	5
Sandstone, generally soft and weathering down, so that good exposures are not often seen	200
Quartzite, changing to sandstone, forming prominent ridge near the summit of the slope. It forms a pine-crested cone that is everywhere prominent. The rock is massive and crumbles under weathering, and is in general indurated enough to be called a quartzite	15

Above this sandstone there is an interval in which the beds are not exposed, and then the massive Carboniferous limestones are seen. It is probable that a fault occurs between this sandstone and the white Carboniferous limestones, as the well-marked, green shales of the Carboniferous are not seen.

The foregoing section is given to indicate the variable nature of the series. The rocks called sandstones do not, however, resemble the sandstones of other formations. The grains are angular, formed of fragments of volcanic rock or a variety of comminuted minerals, and in some places grade into fine breccias. They are really water-laid tuffs; the finer material forming the shales. Associated with these tuffaceous sandstones there are, however, beds of conglomerate whose pebbles are well worn and rounded, formed largely of volcanic rocks, "diorite-porphyries," but including a few pebbles of sedimentary rocks. The relations of the Livingston are well known, the formation having been studied over a very considerable area in Montana. It is quite certain that the rocks represent a period of sedimentation following a Laramie uplift, and record a long period of erosion.

The most interesting feature of the formation as developed in the area under discussion is the occurrence of a bed composed very largely of oyster shells—specifically identified by Mr. T. W. Stanton as *Ostrea subtrigonalis*—a widely distributed species not heretofore known to occur above the Laramie formation.

The relative position of this bed is seen in the following section of the beds exposed between Hensley and Hamilton creeks:

Section of Livingston beds exposed on ridge between Hensley and Hamilton creeks, near Castle Mountain.

	Feet.
Green tuffaceous shale	200
Fine-grained tuffaceous beds, seldom exposed	100
Dark-brown grit	15
Mottled, impure, limy sandstone	5
Shale, greenish-gray in color and of tuffaceous material	15
Oyster bed	2
Alternating beds of brownish grits or sandstones (coarse tuffs) and fine tuffs forming shales	36
Gray tuffaceous shale	30
Coarse green and gray tuffaceous sandstones	25
White hornstone rock	5
Alternating hard and less hard purple and gray tuffaceous grits	200
Tuffaceous grits, weathering readily	75
Dark-purple tuffaceous earths and crumbly sands	60
Brown tuffaceous grits, breaking into small angular bits	30
Volcanic tuff or breccia, weathering brown	25
Tuffaceous sandstone, crumbling to brown, sandy débris	135
Gray limestone, weathering brown	2
Crumbly, brown, tuffaceous sandstones	105
Limestone, dark-gray, weathering brown	1
Tuffaceous sandstones, crumbling to brown sand	62
Dark-blue, compact, cryptocrystalline limestone, weathering brown	1
Tuffaceous sandstones, brown, crumbly	140
Light-gray sandstone	10
Limestone, blue, granular	5
Tuffaceous sandstone	80

	Feet.
Limestone, dark-blue, weathering brown	2
Tuffaceous sandstones with bed of grit in center	200
Limestone	1
Tuffaceous sandstones of varying texture	237
Coal seam	5

This section shows a number of thin beds of limestone in the lower part of the series, which were carefully examined for fossils, but without success.

The Livingston formation is not a coal-bearing horizon, but its beds are of use as indicating the proximity of the coal-bearing Laramie sandstones.

The overlying Fort Union beds, into which the Livingston passes, also carry coal, but they are lignites, soft and crumbly, and of no value when the Laramie coals can be had. This overlying series consists of drab clays and loosely cemented, cross-bedded sandstones. It does not occur in the Castle Mountain district.

MIOCENE.

LAKE-BED DEPOSITS (DEEP RIVER BEDS).

The sediments deposited in the waters of Lake Smith cover a considerable portion of the Castle Mountain area, filling the valley bottom of the South Fork of Smith River and extending up the main stream to the mouth of Fourmile Creek. Their exact extent at the last locality and in the foothill country about White Sulphur Springs is difficult to define, as the beds pass gradually into the fine, volcanic tuffs that cover the lower slopes of the mountain. These lake beds are a part of the sediments which cover the Smith River Valley for many miles northwest of Castle Mountain. They were first described by Grinnell and Dana[1] in 1875, and collections made from the valley were described by Cope[2] in 1879 and later. The beds of this horizon were thoroughly explored by the Princeton expedition of 1891, under the direction of Prof. W. B. Scott,[3] who has published a memoir in which the abundant fossil fauna of the lake beds is fully described.

Within the Castle Mountain area the lake beds are not so well developed as those found far northward in the valley. Below the mouth of Newland Creek two horizons are readily distinguished by their lithological character, and they differ even more markedly in the fossils which they contain, and, according to Professor Scott, they are separated by a probable unconformity. The lower beds consist of a series of well-indurated, cream-colored clays, which attain a thickness of some 200 feet. The line of separation between this underlying formation of clays and the overlying less-indurated sandstones and conglomerates is in some places very well marked. The upper beds consist of

[1] On the new Tertiary lake basin: Am. Jour. Sci., 3d ser., Vol. XI.
[2] Bull. U. S. G. and G. S., Vol. V, 1879. Am. Naturalist, Vol. XX, p. 369, and Vol. XXI, pp. 456, 457.
[3] Trans. Am. Philos. Soc., Vol. XVIII, 1895, pp. 55-185.

rather incoherent strata, much cross-bedded and greatly resembling the Pliocene lake beds so common in the mountain valleys of Montana. They are composed of more or less waterworn material, varying from fine siliceous marls to large pebbles, and forming beds of silt and conglomerate. Within the limits of the area described in this bulletin, this upper series of beds is the one which is shown upon the map, and the lower horizon has not been differentiated. The strata are of heterogenous nature and vary rapidly in kind and composition. Loosely compacted sands and layers of pulverulent volcanic dust, composed mainly of fine glass fragments, alternate with conglomerates and marly, tuffaceous limestones. The coarser sediments show cross-bedding, and the conglomerates are often merely lenses of coarser material occurring in the sandstones. The prevailing colors are white, light-gray, or faint-chocolate, and the exposures are always light and conspicuous in tint. The beds being porous, the areas covered by them are generally arid wastes on which sage-brush and a scanty growth of grass form the only vegetation.

Exposures are seen only along the streams and valley bluffs, the surface being concealed by soil and the recent wash from the neighboring slopes. The greater part of the area south of White Sulphur Springs is a gentle slope of flat bench-land but little elevated above the marshy meadows of the South Fork of Smith River, and so nearly horizontal as to suggest the dry bed of the old lake itself. It is an area that is dry and barren, but capable of cultivation if irrigated. In general character the deposits of Lake Smith greatly resemble the lower part of the Tertiary of the Great Plains area, and the lake beds rest upon the eroded edges of all earlier formations, from the Belt shales of the Algonkian to the volcanic grits of Livingston age. In the vicinity of Castle Mountain the finer-grained beds are very largely formed of particles of volcanic glass. They are in part due to ash showers whose fine dust fell upon the waters of the lake during the activity of the Castle Mountain volcano, and are, no doubt, mostly formed of the same loose, incoherent material washed down and carried by the streams into the waters of Lake Smith.

Within the immediate Castle Mountain region the beds have not proved fossiliferous, although Grinnell and Dana found rhinoceros bones 2 miles south of Moss Agate Springs, a locality somewhere near White Sulphur Springs. The collections of vertebrate remains obtained by Professor Scott are of especial interest in this connection, as they furnish undoubted evidence as to the precise age of the beds in which they occur, and as these beds were formed of the material furnished by the Castle Mountain volcano, the fossils may be accepted as evidence of the exact age of the period of volcanic activity. Of the two horizons differentiated by Professor Scott, the lower is characterized by fossils which are of Lower Miocene [John Day] types, and the upper by a grouping of remains which place it at the base of the Loup Fork epoch of the Upper Miocene, of which they form a well-marked subdivision, a subdivision which is not known in other regions. The European equivalent of the upper series of beds appears to be the Upper Miocene of Sansan and Simoore. The following species of mammals were found by Professor Scott in the lower or John Day series of beds:

Cynodesmus thoöides Scott.
Steneofiber montanus Scott.
Cænopus sp.
Miohippus annectens? Marsh.
M. anceps? Marsh.
M. (Anchitherium) equiceps? Cope.
Mesoreodon chelonyx Scott.
M. intermedius Scott.
Pœbrotherium sp.
Hypertragulus calcaratus Cope.

The upper beds (Loup Fork) present a very different assemblage of species. The list given by Professor Scott, which combines the collections made by the Princeton party and those previously gathered by Professor Cope's assistant, contains the following species:

Canis? anceps Scott.
Chalicotherium? sp.
Aphelops sp.
Miohippus sp.
Anchitherium equinum Scott.
Desmatippus crenidens Scott.
Protohippus sejunctus Cope.
Protohippus (Merychippus) insignis Leidy.
Merychyus (Ticholeptus) zygomaticus Cope.
M. pariogonus Cope.
Merycochœrus montanus Cope.
Cyclopidius sinus Cope.
C. emydinus Cope.
C. incisivus Scott.
Pithecistes brevifacies Cope.
P. decedens Cope.
P. heterodon Cope.
Protolabis sp.
Procamelus sp.
Blastomeryx borealis Cope.
B. antelopinus Scott.
Mastodon proavus Cope.

Professor Scott, in speaking of these remains, says that "the lack of small animals in the collections is very noticeable. The lower beds have yielded but one rodent, and the upper none at all. Only two carnivores, both dogs, have been found. None of the Insectivora or Chiroptera have been detected. The fauna, so far as known, consists, therefore, almost entirely of medium and large sized ungulates," including Protohippus, Miohippus, and Mesohippus, with a new genus of equines which fills the gap between the two earlier forms, several rhinoceroses, camels, a mastodon and other Probocidæ, together with many ancestors of our present species of ungulates.

CHAPTER V.

IGNEOUS ROCKS.

In this chapter it is proposed to give an account of the mode of occurrence of the igneous rocks and their relations to each other and to the sedimentary rocks with which they occur, together with a more detailed description of such localities as are of especial interest.

The petrographic and chemical investigation of the varied rock types is deferred to the following chapter, while the general discussion of the petrologic history of the district, founded upon the facts observed in the field and those brought out by research in the laboratory. will be given in a still subsequent one.

In pursuance of this plan it has been deemed best to divide the rocks into such natural groups as are found by observation to occur in the field—a classification dependent partly on chemical differences in the magmas from which the rocks originated, and partly on their mode of geological occurrence, the last factor having determined, in a general way, the physical forces conditioning their crystallization and textures and thereby their independence as rock types. As has already been stated, in the Castle Mountain mass we have to deal with a greatly eroded and degraded center of volcanic activity. It is, in fact, to use the apt term for such occurrences, a "dissected" volcano. As a natural sequence of this fact, there are presented all the different types of crystallization and structure possible for an igneous magma to assume under the most varied conditions of cooling and pressure. Unlike, however, the great massives of the Crazy Mountains immediately to the southward, there is no such complexity and variability in the chemical and mineral nature of the rocks, except in a comparatively few instances to be noted later. In general, the rocks have been derived from a highly siliceous magma, rich in alumina and alkalies and poor in other components. Therefore the great majority of them belong to the granite family, which, for the reasons just given, exists in every type of structure and development, as granite, granite-porphyry, quartz-porphyry, rhyolite, rhyolitic obsidian, and rhyolitic tuffs and breccias. Associated with these, but in much smaller amount, there are a peculiar augite-diorite, porphyries passing into porphyrites, lamprophyric rocks in dikes and small intruded bosses, and flows of basalt. All of these rocks belong historically to what may be termed a single geologic time-phase of volcanic activity, and with a few exceptions all the other rocks of the district are clearly of sedimentary origin.

Although Castle Mountain no longer presents the slightest remnant of a volcanic cone, the fact that such a cone formerly existed and that active igneous agencies were here at work is strikingly apparent upon an examination of the region; it is advisable, therefore, to consider briefly the evidence, in order that we may better understand the natural grouping of the rocks that follows. It should be borne in mind that of all the varied formations to which geologic agencies may give rise, none are more ephemeral, speaking in a geologic sense, than the exterior products of volcanic activity. Thrown out and piled up in a brief period of time, volcanic materials, from their loose and incoherent state and their frequently fragile and perishable nature, are most quickly eroded and carried away, or metamorphosed by the various forces that act upon them from the moment of appearance. The failure to recognize this fact has often prevented the recognition of their former occurrence in many districts.

Imagine that in a region of already folded and tilted sedimentary strata, there is formed a center of eruptive activity which passes through its various life phases and becomes extinct, and that the mass thus produced is then greatly cut down by the forces constantly striving to bring it to baselevel; it is evident that at the center there would be exposed a core of massive igneous rock representing the former conduit, surrounded by sedimentary rocks more or less altered from contact metamorphism, intruded by sheets of igneous material, and cracked and filled with radial dikes. The effusive and ejected matter would be found at a greater distance, with a more or less roughly annular disposition, lying upon the outer slopes of the general mass, and itself cut by erosion into varied topography. Such a theoretical disposition would, of course, be greatly modified by attendant circumstances, which need not be further enlarged upon.

Just such an arrangement of rocks and material is presented in a general way by the Castle Mountain mass, as may be seen by reference to the map (Pl. III). There is a central core of granite surrounded by upturned sedimentary rocks which are as a rule more or less highly metamorphosed and injected with numerous sheets of porphyry, and in places cracked and filled with dikes. Further from the center and forming the foothills in considerable part, though chiefly to the east and north, are masses of rhyolite and rhyolitic obsidian, filling at times hollows in older eroded valleys and resting uncomformably upon the strata, while other exposures are those of breccias and rhyolitic tuffs, the breccias themselves being overlain in places by rhyolite and cut by dikes.

Such, briefly presented, are the evidences of the former volcanic nature of the Castle Mountain mass, and the resultant rocks fall naturally into the following groups, according to which they will be treated:

I. Massive plutonic rocks of the central mass.
II. Porphyritic rocks of the intruded sheets and dikes.
III. Extrusive rocks in lava flows.
IV. Tuffs and breccias.
V. Igneous rocks of the district not belonging to the Castle Mountain center.

I. MASSIVE PLUTONIC ROCKS.

The massive plutonic rocks of this seat of igneous activity are represented by granite and a peculiar augite-diorite, and they occur in two distinct and separate areas.

GRANITE.

This rock composes the main portion of Castle Mountain, and, as may be seen by reference to the map, its exposure forms a rudely elliptical area about 8 miles long in its greatest diameter and about 4½ miles broad. It forms the solid central core of the mountain, and, as has been shown by the description of the topographic form, it is weathered to a low dome-shaped mass, presenting none of those sharply serrated peaks and spires which are generally so characteristic of the erosion of granitic masses in the younger mountain chains. In part, at least, this is due to its texture, which is, in general, for a granitic rock, rather loose, and filled with miarolitic cavities, thus leading to easy weathering and decay. Nowhere, indeed, does it present that solid, heavy, massive, coarse-grained texture which is generally characteristic of the older Paleozoic and pre-Paleozoic granites—a fact which is in part due to the erosion which has cut these older Plutonic rocks down to deeper levels, where the material has solidified more slowly and under greater pressure, and, in part, to the action of the great dynamic forces of the orogenic processes which have compacted them, closing at the same time all of their miarolitic cavities. The Castle Mountain granite might be compared to the lighter, somewhat spongy form that certain metals assume when merely cast from the melting pot, while these older granites are more like the denser, tougher form the same metal assumes when hammered and rolled.

The term granite is applied to the whole of this great intruded stock, partly because it is composed mostly of granite, the magma in solidifying having commonly assumed the granitic texture and minerals, and partly for the sake of convenience, because the mass is a geologic unit. Nevertheless, within comparatively short distances there are passages into finer-grained porphyritic forms, which, in accordance with the prevailing German usage, would be termed granite-porphyry. The whole mass shows, indeed, in all places a strong tendency toward a porphyritic structure—a fact which will be more fully discussed later.

In general, the granite area presents a smooth, gently contoured surface, diversified by open, grassy meadows, alternating with groves of pines and with few prominent outcrops. About the margin, however, the rock is harder, tougher, and more compact, and breaks into great cubes and blocks, which strew the surface. It is especially around the margin that the craggy castellated piles occur, which, as previously mentioned, have given the mountain its name. In places these crags rise sharply from the otherwise even slopes and project above the forest growth like towers. They do, in fact, often most strongly resemble ruined castles, the regular jointing of the mass giving an effect of broken walls of heavy masonry. They are shown in Plate V, which gives an excellent panoramic view of the margin of the granite area, presenting the general character and jointing of the rock, but which does not show the castellated character of the crags as well as it is sometimes seen.

The height to which these crags rise above the slopes on which they are situated varies considerably, but in general it is not more than 40 to 50 feet. When occurring on the very rim of the mass they often descend sharply on the outer side to much greater distances, commonly into a ravine. Areas on the mountain are also covered with rock piles formed from the natural falling apart of the jointed mass.

The jointing of the granite varies considerably, being in some places in broad, thin plates, and in others in large, rude parallelepipedons or sphenoids, often with incurved faces, the size of the blocks thus formed varying within a wide range from 10 feet long to as many inches. A feature of the granite, particularly in those areas where it passes into a granite-porphyry, is the presence within it of spherical masses, which, on exposed surfaces, by a difference in grain, and also at times in color, are sharply differentiated from the general mass and become noticeable to the eye. They vary greatly in size, from many feet to a few inches in diameter. They are more fully described in the petrographical portion of this work.

As is common in all such granitic masses, it is cut by many white veins or dikes of fine-grained aplite, which are generally but a few inches in width.

It can not be supposed that this huge mass as a whole represents merely the filled up and consolidated canal of an old volcanic throat. It is not only too large to lend color to such a supposition, but the effusive masses which lie outside of it are too small in amount to represent what would in such a case have been a volcanic center of enormous size. It is much more reasonable to conceive that it was originally a huge intruded mass, and that at some point, breaking through the sedimentary cover which has since been removed by erosion, there was then started an outlet for the effusive and projected material.

We have been unable to locate this point precisely, but from the fact that the flows of rhyolite are confined almost entirely to the eastern half of the district, it seems reasonable to suppose that it was situated somewhere along the eastern portion of the mass. The amount of dissection, or, in other words, of denudation, has been so great that it is impossible to reconstruct many of the finer details, such as others have found it possible to reconstruct in similar districts.

Evidences of intrusion.—Evidences of the intrusive nature of the granite are everywhere apparent. Except upon the western slopes, where the beds dip steeply away from the central core, the granite abruptly cuts off the sedimentary strata and abuts against beds of all ages. At a number of localities sheets of porphyry intruded into the stratified rocks are traceable to and into the main granite mass. Moreover, the granite area is everywhere surrounded by a ring of altered, metamorphosed sedimentary rocks, whose alteration is greatest near the granite and decreases with distance from it.

The abrupt cutting off of the sedimentary beds is well shown about the head waters of Alibaugh Creek and also near the town of Castle. At the latter place the workings of the Cumberland mine show that the plane of contact has here an inclination of 55° away from the center of the granite mass. One of the best exposures where the intruded sheets of porphyry may be traced into the granite is seen in the section on upper Fourmile Creek shown in the diagram, fig. 7. The valley is deep and narrow, and in places thickly timbered with small pines (see Pl. VII). The steep slopes are in other places covered with slide rock. Through the upper part of the valley, which has a rapid downward slope, the creek has cut a small, narrow canyon in the valley floor, the canyon being in places 30 feet or so in depth (see Pl. VIII). Through

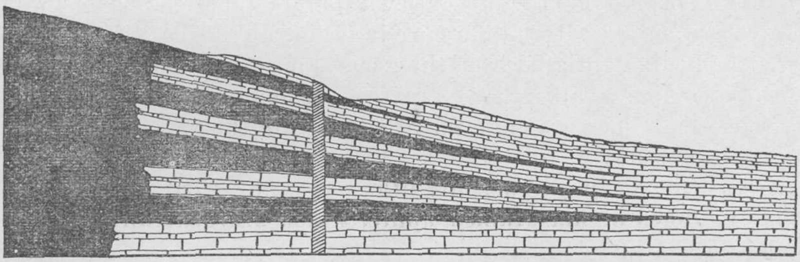
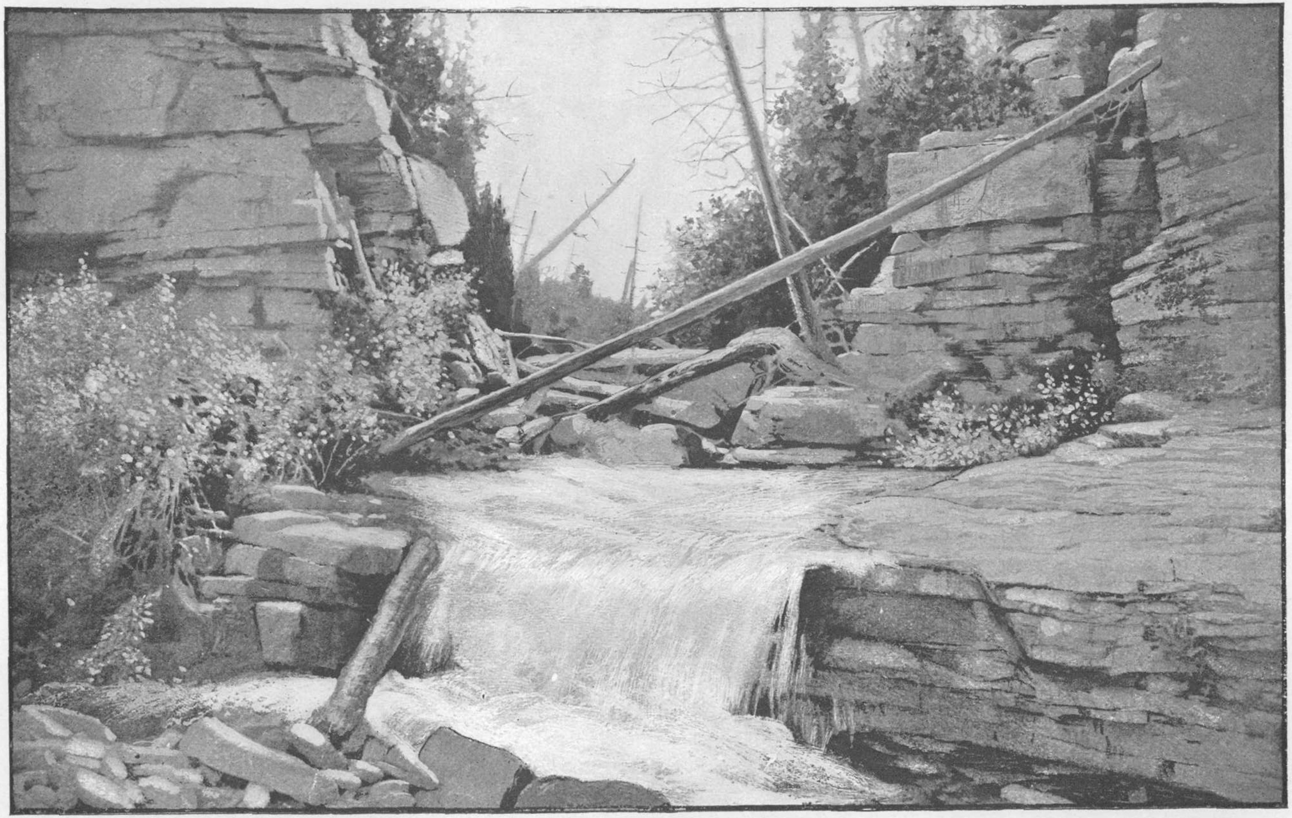


FIG. 7.—Diagram showing tilting of the sedimentary beds by the intrusion of sheets of porphyry from the granite stock, seen on upper Fourmile Creek.

this the stream has a rapid, torrential course, carrying down bowlders, logs, and other drift material. Thus the walls are in general scraped bare and afford good exposures of the rocks. Where the stream crosses the contact with the Belt shales, which dip downstream at an angle of 20°, the latter are split by intruded sheets which project from the granite. Two such, each several feet in thickness, are beautifully exposed at the contact, while others alternate with the Belt formation in ascending the stream to this point. The granite, which is porphyritic and is in fact near the contact a coarse-grained granite-porphyry, rapidly grows denser in grain as it passes out into the sheets, where it eventually assumes the texture and structure of a quartz-porphyry.[1]

To further add to the interest at this point, a photograph of which is given in Pl. IX, both the Belt shales and the intruded sheets of porphyry are cut across at right angles to the course of the stream by a lamprophyre dike of augite-vogesite some 5½ feet in width. The

[1] The terms porphyry and porphyrite are used in this work to designate, without reference to their age, such dense holocrystalline porphyritic rocks as are found in intrusions.



FALLS OF UPPER FOURMILE CREEK.

nature of the exposure is such that the passage of the granite out into the intruded sheets and the torn and opened ends of the sedimentary beds can be seen in one continuous exposure.

Other examples of the connection of the intruded sheets with the granite mass may be seen in various localities, though in none are they so well exposed as in that just mentioned. While the abundance of these intrusive sheets at Castle Mountain forms a striking feature of the general geology, the paucity of dikes is noticeable, and few dike-like apophyses of the granite cutting the adjacent rocks have been observed.

DIORITE.

This stock of intruded rock, as shown on the map (Pl. III), is a rudely circular mass about a mile in diameter, with an apophysis thrust out to the northeastward, through the middle of which the upper waters of Bonanza Creek have cut a deep ravine. The mass possesses the coarse grain and solid texture typical of an abyssal igneous rock which has solidified under great pressure. Nevertheless, at its outer edge, and especially toward the western border, as typically shown in the exposures on the hill above Blackhawk, west of the Legal Tender mine, it passes into a denser form and becomes porphyritic. It then weathers out into crags, and has a jointing in all respects like the granite, possesses similar spheroidal masses with a circular parting and denser grain, and in every way shows its consanguinity and genetic relationship to the neighboring granite mass.

The coarse-grained central portion of the intrusion seems to weather away most easily. Indeed, as shown in a prospector's trench on the open meadow crossed by the wagon road from Blackhawk to Robinson, it is in places thoroughly rotted by superficial decay to a soft crumbly mass, easily disintegrated between the fingers. Somewhat deeper, however, it is beautifully fresh and well preserved, as shown by the material thrown out from a prospect shaft in this meadow to the southeast of the present road. The material exposed by the cutting made for the road just above Robinson is also very fresh and unaltered.

The character of this rock changes toward the outer edge, becoming steadily more siliceous until at the boundary it assumes the composition of a quartz-diorite-porphyrite, though rather low in quartz. It is abundantly cut by aplite and quartz-porphyry dikes which have the composition of the granite, as will be shown later. Some of these dikes may be seen as low, small ridges crossing the open meadow and the wagon road just mentioned, with an east-and-west trend, which if prolonged would carry them into the granite mass. A fine example of the aplite dikes may be seen among the material thrown out at the prospect shaft mentioned above, the pale-yellow color and fine grain of the narrow dike contrasting strongly with the dark-gray, coarse-grained diorite.

The exact relation between this intruded stock and the great granite mass is not absolutely certain, since they nowhere come into contact, being separated by a large block of upturned Belt shales full of intruded sheets of porphyries, as shown on the map. Since, however, it is cut by numerous dikes which trend toward the granite and have its exact chemical and mineral nature, while the granite is not cut by dikes of rock of the nature of the syenite, as well as for other reasons which will be discussed later, it is assumed to be the older of the two. This assumption seems also to accord with recent chemical work in general petrology, and while no further evidence can be adduced in favor of it, it serves as a working hypothesis for the explanation of the geologic history of the district, and best accords with all the facts observed.

CONTACT METAMORPHISM.

The intrusive masses of Castle Mountain have strongly marked their entrance into the sedimentary beds by the amount of metamorphism which they have effected The Belt shales near the contact are baked into tough, hornstone-like rocks with an extremely dense grain and conchoidal or splintery fracture like that of jasper. They have lost their fissile character and have a coarse jointing, so that under the blow of the hammer they break up into rhombohedra of irregular shapes. Instead of the black or dark-gray color so frequently shown, they are chiefly reddish or greenish in tone, with a banded appearance, which is all that remains to distinguish the former bedding planes. They resemble strongly certain varieties of adinole formed by the contact action of intruded diabases on the slates of the Hartz Mountains in Germany.

Nowhere in the metamorphic zone has there been observed that kind of contact metamorphism which produces in clay-slates a regular spotting of the metamorphosed rock due to the formation of small nodules made up by collections of minerals, and which is a common phenomenon to be observed in the metamorphism of clay-slates.

The metamorphism is most clearly seen, of course, in the immediate contact with the igneous rock. The changes become less perceptible in passing outward from it, and so gradually that no exact lines can be drawn between the altered and unaltered areas. The width of the metamorphic zone varies somewhat in different localities, according to circumstances. It is, however, nowhere very great, a quarter of a mile fully sufficing to carry one into the area of unaltered shale or slate. Considering the great size of the granite intrusion, this is a rather narrow zone. The reason for this is perhaps to be found in the fact that, as already shown, the granite area does not represent in its entire mass the filling up of a previous volcanic conduit, but is largely a single intrusion. Around volcanic throats, metamorphism is apt to be intense from the continued supply of heated material from below, while in a single intrusion the heat is only that initially furnished. Thus in

INTRUDED SHEETS AND DIKE ON UPPER FOURMILE CREEK.

the latter case the amount of metamorphism may be small, and indeed, as has been shown in the case of some laccolites, may be nearly wanting. The result is also dependent upon other factors, such as the mineralizing vapors of water, fluorine, etc., whose presence in greater or less amount would naturally influence the result.

The valley of the main upper fork of Fourmile Creek (see Pl. VII), which has been previously mentioned as evidencing the connection between the granite and intruded sheets of porphyry, is one of the best localities showing the metamorphosed character of the Belt formation (see Pl. VIII). The heat and vapors from the great number of intruded sheets has, without doubt, also aided this action. The steep slopes of this valley, in places often thickly covered by dense growths of small pines, and in others open and covered with slide rock, show numerous exposures of the sedimentary strata. These outcrops are formed of hard, dense, and jagged rocks of the character already described, and differ most strikingly from those of other areas shown on the map, where the Belt shales are unacted upon by contact metamorphism. At such places smooth, rounded slopes prevail and actual outcrops are difficult to find, only the soil, filled with fine fragments of disintegrated shales, showing the country rock beneath. Outcrops and consequent topography of a kind similar to that on Fourmile Creek are also found around the upper head valleys of Cottonwood and Willow creeks; descending from the smooth upper slopes of the granite, the streams immediately cut deep ravines in the metamorphosed sedimentary zone, and these widen out into smooth open valleys as they enter the softer, unaltered shales of the Belt formation.

The action of the intruded masses upon the limestones with which they come in contact is also marked, though that produced by the diorite area is much the more so. Thus, at the divide at the head of the eastern upper fork of Willow Creek, in the neighborhood of the Grasshopper mine, the Silurian (?) limestones are brought against the granite, and within a few rods they show considerable alteration in color and crystallization. In other localities, as at the Cumberland mine above Castle, the limestones are greatly altered, partly, also, from intruded sheets and from hot mineralizing solutions which have deposited the ores within them.

The most striking effects produced upon the limestones by the igneous intrusions are to be found in the neighborhood of Robinson and of Blackhawk, where the metamorphism is due to the diorite mass. The limestone hills around both of these localities have been bleached and whitened into marble, which is, in places, as in the road-cutting opposite Blackhawk post-office, very coarsely granular, yielding broad cleavage plates of calcite an inch or more across. In places, also, various silicate minerals, such as garnet, phlogopite, vesuvianite, and pyroxene are to be found, due to the metamorphic action upon the silica and alumina of the former sand and clay mixed with the impure limestone, containing lime, magnesia, and iron. Excellent examples of this are found in the material thrown out of the prospect shafts on upper Bonanza Creek, a little below the point where the present wagon road from Blackhawk to Robinson leaves the stream.

It is in the areas of altered limestone that the deposits of ore which have made the Castle Mountain region so well known in Montana are found. This phase of the subject will be more fully treated in the chapter on the mining resources of the district. The fact, however, is prominently brought to one's attention in viewing the country below from any of the high spurs of the mountain which give an outlook to the eastward. That the contact rock is the place to seek ore has been well known to the miners and prospectors, and this fact has caused these areas to be thoroughly explored. Looking across the country the contact line on every ridge may be seen, marked by the white heaps of impure marble thrown out from the prospectors' trenches.

II. INTRUDED SHEETS AND DIKES OF PORPHYRY.

In parts of the Castle Mountain area intruded sheets occur in such great number that it has been found impossible to depict them all upon a map of so small a scale, and hence, in some portions of the district, the sheets shown on the map should be understood as representing a much greater number. Especially is this true of the upturned block of Belt shales which separates the granite and diorite areas. The open hill between the heads of Fourmile and Checkerboard creeks is crowded with these sheets, only a few of which can be shown on the map. They range in thickness from a foot to 3 or 4 feet. Their connection with the granite in the Fourmile Valley below the hill has already been mentioned. The mountain spurs above Castle are full of intruded sheets, as are also the hills above Blackhawk in the metamorphosed limestone and Belt slates. Sheets of porphyry derived from the granite mass also occur in considerable numbers in the Cretaceous beds below the town of Castle. At this point the strata are steeply upturned, and the greater resisting power of the igneous rocks to weathering processes causes them to stand up in combs crossing the ridges. As a rule the intruded sheets of the region do not extend far out from the central core, but are confined to the immediate vicinity of the granite mass. The absence of intrusive sheets in the upturned rocks along the western flank of the mountain is to be explained partly by their attitude. These sheets all show little if any folding subsequent to their injection.

As previously mentioned, segregated masses occur in the granite and diorite areas, which differ from the inclosing rocks in composition and texture. From certain observed facts it seems evident that similar masses exist also in the intruded sheets and in extrusive lavas. In these, however, they do not possess the spherical form, but appear to be drawn out into flat, lenticular, or spindle-shaped bodies, as if, having formed while the molten masses were still in a very liquid condition, they had been stretched, when the intrusions and flows occurred, with a more stiffly viscous material. Thus when the outcrops of flows or the edges of upturned sheets occur, at first sight these segregated masses appear like dikes cutting them, and their real nature is to be seen only after a more detailed study of the exposures. This simulation of a dike is often aided by a difference in the weathering and erosion of the varying rock masses, which causes either the main rock or the inclusion to be prominent.

DIKES.

Comparatively speaking, there are not many dikes to be found in the Castle Mountain area, and consequently those that occur play but an insignificant rôle in its structural geology and in the formation of its topography. There is thus a marked difference between this region and that of the neighboring Crazy Mountains, whose vast and complicated system of dikes forms so marked and distinguishing a feature of its geologic structure. The explanation of this fact is probably to be found in the circumstance that eruptive activity began to manifest itself in the Castle Mountain district after the sedimentary strata had been already upturned and eroded, as previously pointed out. Thus areas and lines of weakness already established became the seat of intrusions, which therefore took place without extreme shattering of the strata and consequent formation of dikes. It will be noticed that those which do occur have a general radial disposition with respect to the central mass, a phenomenon often observed in other regions where they are more numerous around eruptive masses.

Those which are found, however, illustrate very well several points of interest which render them worthy of a detailed description. They may be briefly divided into two classes—dikes of acidic and of basic rocks, the former rich in silica, alumina, and alkalis; the latter poor in silica and distinguished by large amounts of lime, magnesia, and iron oxides. Thus the molten masses forming the dikes of the first class have crystallized into rocks composed chiefly of feldspar, often with accessory quartz and with small amounts of mica or hornblende.

Acidic dikes.—The rocks of these dikes are light-colored porphyries with large phenocrysts of feldspar. According to the different physical conditions under which they have cooled and crystallized, they have assumed various textures, and are to be distinguished as microgranites, granite-porphyries, quartz-porphyries, and feldspar-porphyries, often grading into porphyrites by an increase in the amount of soda-lime feldspar. Examples of the microgranites are found in the narrow dikes cutting the diorite, the rocks having the composition of the main granite mass. Types of the granite-porphyry are found in the big dike, 12 to 14 feet wide, which cuts the tilted Belt shales on the mountain side on the main head of Fourmile Creek, and which forms so conspicuous a feature of the view looking up this valley from the point where the present road from White Sulphur Springs to Castle leaves Fourmile Creek as it makes its abrupt turn to the southward (see Pl. III, geologic map, and Pl. VII). The Belt shales, which are here indurated and altered, have been eroded so much faster than the dike that the latter rises for a long distance above the steep slope in a great wall 20 to 30 feet high and 12 feet broad.

Another example is found in a somewhat similar dike which has also been brought into prominence by erosion, and forms a wall seen upon the hillside north of the present road from White Sulphur Springs to Castle, a short distance above Reed's ranch on Fourmile Creek. This dike has cut through the Cambrian limestones, which, by the action of its contact, have been for some distance whitened into marble. The rock itself is distinguished by the large porphyritic crystals of orthoclase feldspar which it carries and which become smaller and nearly disappear at the contact. A dike of exactly the same kind of rock, with similar large phenocrysts, appears on the hill to the northeast of the one just mentioned, and it may, indeed, be its continuation, though positive proof on this point is lacking.

A dike of porphyry, 30 feet wide, is seen cutting the green Carboniferous shales a short distance below Reed's ranch on Fourmile Creek. The rock belongs to the acid series of dikes and has produced but little alteration in the adjacent shales.

Dikes of porphyry, inclining to quartz-porphyry, also cut the diorite mass, as shown on the map. (Pl. III.) They appear as low ridges cutting across the grassy slopes of the upland meadows, through which the present road from Blackhawk to Robinson passes. The rocks of which they are composed are greatly weathered, so that their exact nature is uncertain.

Three parallel dikes of porphyry are to be found cutting through the upturned Cambrian limestones which form part of the western limb of the synclinal fold to the northeast of Blackhawk. They are reddish rocks, and at a distance appear clearly as low walls about 5 to 6 feet wide, crossing the light-colored limestone hill. They trend to the northeast and eventually die out in the Dakota sandstones and shales. In composition they are feldspar-porphyries passing into porphyrites.

Porphyry dikes are also found cutting the altered sedimentary rocks near the granite contact northwest of Castle, between that town and Alibaugh Creek. Another dike of similar character occurs on the slope west of the stream.

In passing over the hill, the road from Blackhawk to the mouth of Checkerboard Creek follows the most southern of these dikes in descending to the level Cretaceous flat of the trough of the syncline. It is noticed that these dikes have effected almost no contact metamorphism in the adjacent limestones.

Dikes of somewhat similar rocks are also found in the upturned Cretaceous beds below the town of Castle. It is also probable that the tilted masses of Belt shales which rest against the granite on the northeast side between the granite and diorite and to the north of the latter are cut by acid dikes as well as filled with intruded sheets. These areas have been most extensively prospected by the miners, and the mines of Robinson and Blackhawk are mostly to be found in them. In some of the prospect shafts contacts of igneous rocks with the sedimentary strata are to be seen, which would indicate dikes both of acid and basic varieties, but the exposures at the surface are either covered or of such a nature that they do not afford positive evidence.

Basic dikes.—Dikes of the second or basic class are rarer. They form heavy trap-like rocks of a black, dark-gray, or greenish color, are usually dense in texture, and carry porphyritic crystals of mica, augite, hornblende, or olivine. They belong to that class of rocks to which the name "lamprophyre" has been given, and which are to be found in close connection with areas of eruptive volcanic activity. Usually they are found to be the very latest phenomena of intrusion and cut the other volcanic rocks with which they come in contact. This is also the case in the Castle Mountain district, though, as they are few in number and extremely subject to subaerial decay, only a few such instances have been observed. For this reason, as pointed out by Iddings,[1] when these rocks have reached the surface and formed lavas they are among the first of the volcanic products to be carried away by denudation. As erosion has been so extensive at Castle Mountain, such extrusive masses, if they formerly existed, have been mostly carried away; yet this has not been invariably the case, and we will endeavor to show later that in some cases, at least, the extrusive equivalents of these lamprophyres still exist.

Vogt[2] has recently pointed out that such basic rocks are liable to carry sulphide ores as masses segregated from the molten magma. Instances of this have also been observed at Castle Mountain, as in the case of the Little May prospect shaft, where chalcopyrite occurs in such a dark-greenish decomposed rock. The prospectors, indeed, seem to have a practical knowledge of this, since it is observed that wherever these rocks occur they are apt to be extensively prospected, especially if somewhat decayed, since they are then more easily worked.

It is well known that under atmospheric and aqueous agencies these rocks are liable to two kinds of alteration. In the first they become rich in carbonates; in the second kaolin is formed, often to such an extent that of the dike only a mass of clay is finally left. This latter process seems especially true of that variety of lamprophyre rocks which consist chiefly of orthoclase with much biotite, and which are known as minettes or mica-traps. These are not found in the Castle Mountain district, and the alteration of such lamprophyre dikes as do

[1] Origin of igneous rocks: Bull. Philos. Soc. Washington, Vol. XII, 1892, p. 168.
[2] Zeitschrift f. prak. Geol., Vol. I, 1893, p. 4 et seq.

occur is of the first class—the alteration into carbonates, especially calcite.

One example of these dike rocks is found on the west side of Willow Creek, where the dike has a northerly trend and cuts somewhat altered Belt shales not far from the margin of the granite mass. It occurs in a little saddle below an irrigation ditch which carries water from Willow Creek down a dry gulch to the plain to the westward. It has been prospected, and some fresh material has thus been thrown out. The rock is black and heavy and contains crystals of yellow olivine; it consists chiefly of augite, and is related to the monchiquites. On upper Fourmile Creek, a view of which is shown in Pl. IX, is another fine exposure of a lamprophyre dike. This view shows the east wall of the little gorge cut by the creek. A sheet of quartz-porphyry, 30 feet thick, is underlain by 20 feet of dark-gray and purple, much altered Belt shale, dipping 20° downstream, and resting upon a porphyry sheet that is an extension of the granite mass. These rocks are cut by a dark-colored dike 5½ feet wide.

Another dike of basic character is found crossing Fivemile Creek above the limestone canyon. It cuts the rhyolitic breccias which form the stream bluffs and the limestones that form the slopes to the east. The rock is so greatly altered and decayed, however, that its precise petrographic nature, beyond the fact that it belongs in this class, can not be determined.

Another dike of a similar nature is found in the Cambrian strata on the hill north of Fourmile Creek, at the point where the stream turns to the westward. Its trend is such that it must intersect the large dike with big feldspar crystals previously mentioned, but the intersection is not exposed, and their relative ages can not be determined.

That the peculiar basic magmas which form the rocks of this class need not necessarily occur only in dike form, as has been urged by some authors, is well shown by a massive intrusion in the shape of a small stock just below the mouth of Fourmile Creek. Smith River has cut through the mass and laid bare excellent exposures. This intrusion has occurred in Cambrian limestones, but the contact is clearly defined only on the north side; elsewhere the limestones have been covered with rhyolitic tuffs and the alluvium or lake beds formed by their wash. Where the contact is exposed the mass is seen to have locally altered the adjacent limestones by contact metamorphism. The rock is dark-gray in color, fine-grained in texture, and carries phenocrysts of biotite. It consists chiefly of biotite and orthoclase and is most nearly allied to those rocks of this class which have been called minettes.

Besides these dikes which have been mentioned and which all belong to the Castle Mountain center of eruptive activity, there occur in the Cretaceous strata in the southeastern portion of the district a number of dikes whose genetic character is quite distinct from them. Some of them belong to the Crazy Mountain period of activity, and by their mineral and lithologic character may be readily referred to Crazy Mountain types. One such has been covered, after former erosion, by the great rhyolite flow to the southeast of the diorite area. Others, owing partly to their mineralogic character and partly to their decayed condition, are of uncertain origin. Such, for instance, is one whose outcrop branches and winds in a most curious manner, cutting the Cretaceous strata and intruded sheets of the theralite south of Bonanza Creek, about two miles above the Musselshell River.

III. EXTRUSIVE ROCKS OR LAVA FLOWS.

RHYOLITE.

These occur only in the eastern half of the district, as may be seen by reference to the map (Pl. III). They consist of two varieties of rock—rhyolite, the effusive equivalent of the granite, and basalt. It is probable that the rhyolite flows had originally a much greater extension than they now possess, having been cut away by erosion. The masses that remain are generally of great thickness in proportion to their size, and are remnants filling old erosion hollows. They grade from holocrystalline rocks, practically the same in structure, texture, and mineral composition as the intrusive quartz-porphyries, through semicrystalline forms having spherulites, flow structures, etc., to glassy pitchstones. These variations occur at times in the same mass. In appearance they are reddish to gray colored, at times nearly white, usually very dense, with conchoidal fracture. Occasional small crystals of quartz and feldspar may be seen as phenocrysts. They are often extensively jointed so that the talus slopes resulting from their denudation are composed of small angular fragments.

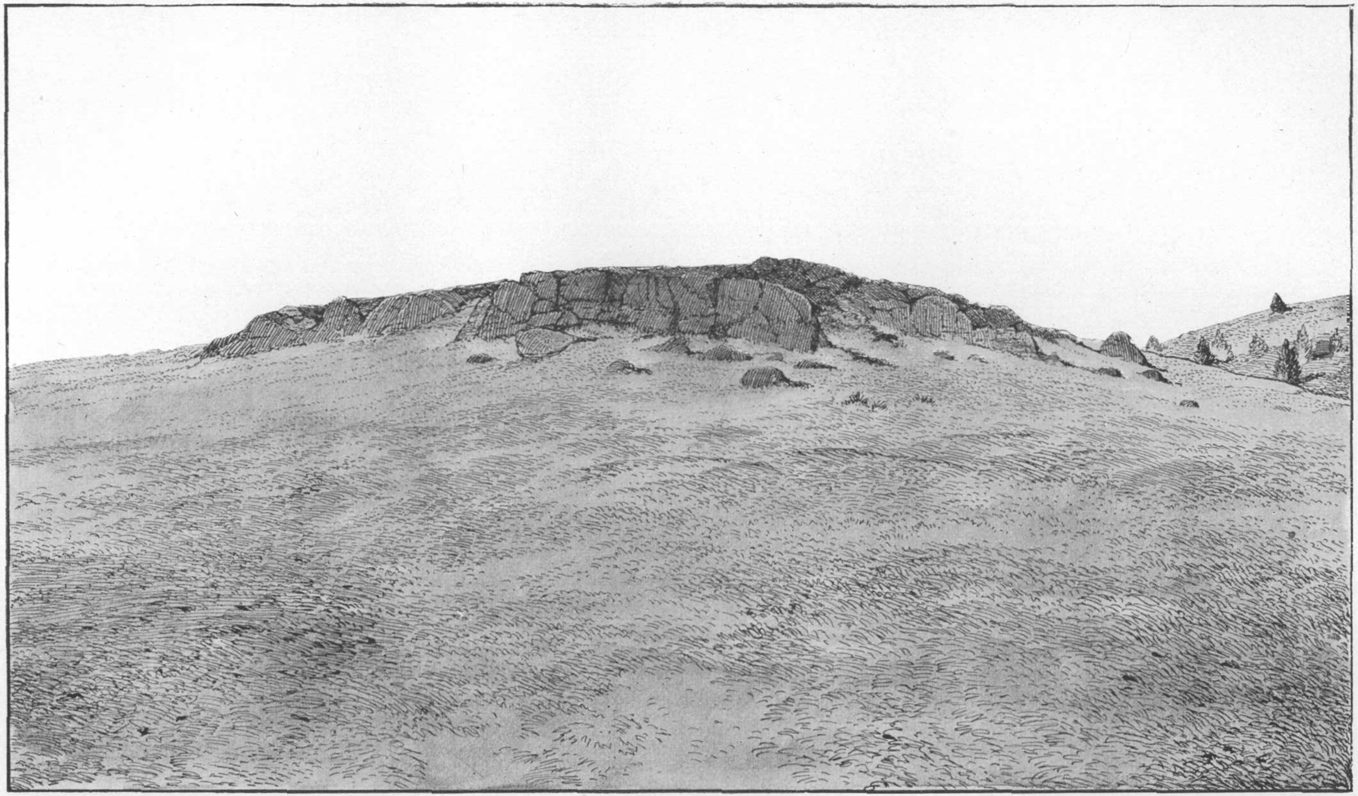
The greatest mass of rhyolite which has been found in any one place is that which occurs northeast of Fourmile Creek, opposite that portion of the stream where several branches from the south flow into it. This mass has great thickness. Near the stream it rests upon rhyolitic breccias which are perhaps 75 feet thick, and from this point it rises to the summit of the hill, 1,000 feet above the stream. The breccias upon which it rests are greatly indurated and have a massive appearance and jointing. The rhyolite itself varies from place to place in its texture and crystallization. Half way up the hill the rock has a beautiful, pronounced flow structure, dark-gray or black lines in a lavender-colored rock, showing that the plane of flowage dipped at 60° away from the mountain. Near the top of the hill the rock becomes dense and massive and no appearance of flow structure is to be seen. The mass extends down the slopes toward the north until its outcrops are lost in glacial drift and the débris of rhyolitic breccias. In places masses of a more coarsely crystalline texture occur, and these are apparently of a similar nature to those found in the granite and intruded sheets, as already mentioned. The edges of the southeastern portion of the mass show that it rests unconformably upon upturned sedimentary rocks.

Another very similar mass of rhyolite, 250 feet thick, which is seen to occupy an old erosion hollow, is found about 3 miles north and slightly east of the above, not far from where the road from White Sulphur Springs to Martinsdale crosses Fourmile Creek. The rock is very dense and microcrystalline; lines of flowage have not been observed in it. It forms the crest of a prominent hill and rests on upturned and eroded Cambrian strata.

Another locality for rhyolitic rocks occurs on the north side of Smith River, about a mile below the point where Fourmile empties into it. It is here left as a series of caps on little points which form part of the lower slopes of the limestone masses that rise in the hills on this side of Smith River. These little caps have a parallel east-and-west trend, but appear to be mere remnants of a much larger mass. The rock is very white and dense, with small phenocrysts of quartz.

A great flow of rhyolite also occurs to the south of Bonanza Creek in that portion of the foothills included by its sudden turn to the south. The mass lies on the southeast slopes of these hills, as shown on the map. In the stream hollows to the east it has considerable thickness, and it thins out toward the top of the ridge, being cut off by erosion. The rock has a platy structure, dipping down hill, and where it is cut by a fork of Bonanza Creek the exposure shows columnar parting. This rhyolite-flow rests upon upturned and eroded Cretaceous sediments, largely Dakota sandstones, together with shales penetrated by dikes of Crazy Mountain types of rocks. Nowhere were breccias observed beneath the flow. This indicates either that the earlier ash and breccia showers were completely removed from this area by erosive agencies before the outpouring of the rhyolite, or that no breccias were thrown out upon this side of the volcano. The entire absence of breccias from the surface of this part of the mountain may, however, be due to the very complete dissection and erosion that have taken place since the cessation of volcanic activity. Moreover, while the outbursts of fragmental material were undoubtedly the earliest manifestations of volcanic energy in the district, yet this particular area may not have been so covered. The rock itself differs somewhat in its appearance from the others previously mentioned. It has a buff-colored, felsitic groundmass with abundant included crystals of sanidine, white in color, which give it a strongly marked porphyritic appearance. The rock found in place is somewhat friable and decayed. Great quantities of it appear in the form of glacial pebbles in the stream valleys below, and this material is often fresher, with a dense, tough, felsitic groundmass of a greenish-gray to yellowish-brown color, with small included crystals of feldspar and quartz.

Rhyolitic flows are found resting on rhyolitic tuffs and breccias above the canyon that Checkerboard Creek has cut in the heavy-bedded



OBSIDIAN (RHYOLITE) LAVA FLOW ON NORTH FLANK OF CASTLE MOUNTAIN.

Carboniferous limestones. The several forks of the creek which unite just before entering the canyon have cut down through these masses, giving excellent exposures. The most northerly of them is a very dark rock, microcrystalline, with megascopic quartz phenocrysts.

The other two masses are mostly glassy and are very clearly flows or portions of one original flow. In the accompanying plate (Pl. X) a view is given of the western wall of the most southerly of these two masses. The exposure is about 40 feet thick, and the rock is dark-gray in outcrop, weathering in great blocks with rude columnar parting, which is shown in the view, made from a photograph. The rock composing this flow is peculiar; in the main it is a grayish, lithoidal rhyolite, somewhat porous in texture, consisting mostly of glass. In this are embedded great quantities of a black glass in small angular fragments, which is a pitchstone, since it contains 4½ per cent of water. These fragments vary in size from a few inches down. In appearance they strikingly resemble pieces of the Cretaceous coal found in the region. As this coal occurs a short distance to the southward, where it has been worked, drift fragments of it and the pitchstone are found, which at first glance can not be distinguished. The rock is also much cracked and is filled with lamination planes, which complete the resemblance. Besides these fragments of pitchstone, the rhyolite flow contains also occasional small fragments of limestone and shale, which appear to be very slightly metamorphosed. All of these included materials are arranged in a very evident flow structure, easily seen on the face of the outcrops, but too large in scale to show well in hand specimens. There are also planes of lamination in the mass, which cause it to break much more readily in these directions.

The rhyolite is therefore a flow breccia. Such an arrangement in a lava, in which it consists of mingled portions, differing in colors and appearance, but chemically alike, is called the eutaxitic structure, and in the present case its origin can be easily explained by supposing that, as the rhyolite lava was extruded, a certain layer of it cooled and solidified as pitchstone, while the remainder, as a stiffly viscous mass rolling slowly onward over itself, crushed the solidified layer and kneaded it through its mass. Although fluid enough to move, it was not hot enough to refuse the pitchstone fragments, which therefore retain their original shape.

BASALT.

Flows of basalt occur in four distinct areas in the Castle Mountain region, as shown on the map. One of these extends in a long mass sloping downward to the southeast from the hills to the west of Lake Creek and between it and the road to Neihart. The source and geologic relationships of this mass are uncertain, beyond the fact that it is an extensive lava flow resting on Belt shales.

By far the most considerable body of this rock that occurs in this district, however, occupies a central position in the level, open valley of the upper part of the north fork of Smith River. It is a large flow, covering about 6 square miles In general its surface is quite uniform; it is thickest toward the northeast and tapers to a very thin edge to the west and south. The contour line shows that it has been cut out slightly along the middle in a north-and-south direction, following the drainage of the branch of Smith River that crosses it.

While the exact source and geologic history of the remnants of basaltic flows are so often doubtful, this is not the case with the one under discussion. Its origin and the fact that it is the very latest manifestation of volcanic activity in the Castle Mountain area are evidenced in several very unmistakable ways. The latter point is shown by the very shallow canyon which Smith River has cut in the mass. Looking across the plain, one sees no evidence of the river whatever, only a level stretch of table-land; but on crossing it the river is suddenly found running in a narrow box canyon from 10 to 20 feet deep, the walls of which are often perpendicular. Evidently the river has but recently commenced this work, and has not yet succeeded, although it has a rapid and nearly torrential course, in cutting its gorge through the basalt. This is the more marked when the configuration here is compared with the comparatively deep and wide valley cut in limestone strata below, before the river debouches on the plain near White Sulphur Springs.

Another evidence is afforded by the basalt itself, which in several places, as near the mouth of Fivemile Creek, for example, is seen to have rested upon the alluvial clay deposits formed by the washing and degradation of the rhyolitic tuffs and breccias previously shown to form so large a proportion of the Tertiary lake beds. Where the thinned-out edge of the basalt flow has come upon these clays they are reddened, toughened, and have a brick-like appearance.

That the extent of the flow, as delimited upon the map, corresponds closely to its original boundaries is indicated by a more vesicular condition of the rock, by its thinning out near the margin, and by the occurrence of masses of tachylite or basaltic glass seen near the mouth of Lake Creek.

The greatest point of interest in connection with this flow is its place of origin, which was Volcano Butte. This mass rises as an isolated, conical butte about 500 feet above the nearly level, gently contoured, open valley, and forms a dominant and striking feature in the landscape. It is the eroded remnant of a former volcanic cone, as is evident from its position, topography, and relationship to the flow which extends from its foot, as well as from its internal structure It consists in the main of highly pumiceous, brecciated material, mingled with small "bombs" of scoria in great quantities, alternating with denser solid flows, which pitch sharply down toward the plain. The scoriaceous material is filled with small angular fragments of Belt shales, reddened and baked, while these rarely or never occur in the denser flow rock. Thus it would seem that in breaking through the upturned shales and forming a conduit the blown-up, brecciated, scoriaceous material, which indicates explosive action, became filled with fragments of the soft shales, and the conduit having once formed, the material which followed, forming the flows, had a freer exit, and therefore does not contain them. The former presence of the vapors which so generally accompany volcanic activity is well shown by the altered and highly amygdaloidal condition of the scoriaceous masses whose pores are filled with calcite and zeolitic materials.

Evidences of eruptive activity in extremely basic lavas having been found at this point, careful search was made for basic breccias of this material in the vicinity, which resulted in the discovery of a few small exposures on the hill immediately south of the mouth of Fivemile Creek. These consist mostly of small, round, vesicular, basaltic bombs, mixed with a basic cement, the breccia resting on the upturned and eroded Cambrian limestones. The exposures are very small and thin and are only the vanishing remnant of former masses. They are in close connection with remnants of rhyolitic breccias and flows, and, as far as the outcrops would warrant an inference, were judged to be resting upon them. They are of great value, however, in strengthening the evidence deduced at Volcano Butte as to its former explosive nature. The whole evidence collected goes to show, however, that the life of this small subsidiary volcano, which broke out on the edge of the great Castle Mountain mass long after it had become extinct as an active volcano, was comparatively short, and that after building its cone and ejecting upon the surrounding country a limited amount of material, it exhausted its activity in the great lava flow which broke through its western side and spread over the floor of Smith River valley.

Another small basaltic cone rises above the level valley floor some miles east of Volcano Butte. It resembles the latter very closely, and a lava flow from it covers the eastern part of Volcano valley as far as Spring Creek; the flow rests on fine rhyolitic tuff and is well exposed about the head of the North Musselshell and the forks of Richmond Creek.

It may be further stated that the basaltic rocks mentioned in the foregoing occurrences are of the usual black or very dark gray, dense, heavy type, in places somewhat vesicular, and usually much jointed. Fine columnar parting, so often observed in basalts, was nowhere found.

IV. TUFFS AND BRECCIAS.

In no way does an extinct volcano leave more unmistakable proofs of its former activity than by accumulations of tuffs and breccias. Since these, however, as a rule are the most recent deposits of a country and mantle all the other formations, they are also the first to be carried away by subsequent erosion. At Castle Mountain, as has been shown, the amount of erosion since the volcanic period has been very great, and hence these ejected materials have been largely removed.

It is probable that a very considerable cone must have at one time existed here; if so, it has nearly entirely disappeared and we can only surmise its size and position. The dissection by denudation has indeed been complete, and, speaking from a geologic standpoint, only the rapidly vanishing remnants of the former masses of breccias and tuffs are left. Fortunately, these remnants remain as invaluable documents to show the former history of the volcano, but even they in a short geologic cycle will have utterly disappeared.

Consisting of light, rather incoherent particles, these rocks have been readily removed by surface waters, and it is largely due to this that the old lakes were rapidly filled up. The lake beds, indeed, consist largely and in places almost wholly of this material, as does also, to a very considerable extent, the alluvium of the present stream channels in those areas where tuffs and breccias abound. As has been pointed out in the description of the Miocene lake beds, it is difficult, indeed, at times to tell whether one is dealing with this material in its original position, where it fell, or with sedimentary deposits formed by its removal, the smooth, rounded surfaces without outcrops increasing the difficulty. Nor does microscopic examination aid in discrimination, for undoubted tuffs and lake beds are often found to consist of the same material, minute fragments of glass mingled with equally minute fragments of comminuted shales and other sedimentary rocks. In several localities, therefore, where these deposits border each other the exact boundaries must remain somewhat uncertain.

The area where these tuffs and breccias occur is shown on the map, and it will there be seen that it is chiefly to the north and east of the great granite mass. One interesting locality is on upper Fourmile Creek, on the north side of the stream, near the point to where several tributaries run in from the south. It has already been mentioned that the upper part of this hill is composed of a great thickness of rhyolite. In the canyon cut here by the creek this rhyolite is seen resting on heavily bedded rhyolitic breccias. The breccia is from 75 to 100 feet in thickness and has been greatly indurated, so that it breaks, joints, and erodes similar to a massive rock. The cement is of a greenish color, and this is filled with fragments of shales, limestones, and at times of igneous rocks. These fragments have been more or less altered; the igneous rocks, which appear to have been of porphyritic nature, are usually greenish in tone, and recall fragments of porphyritic rocks which have been altered by aqueous vapors at high temperatures.

Another excellent exposure is found near one of the upper heads of Checkerboard Creek, the breccias forming a small hill whose light-green color makes it a prominent feature of the landscape. On the northwest side this hill has been cut down by a little drainage into a cliff about 150 feet high. The breccias rest on upturned and eroded Dakota sandstones (quartzites?). The rock formed by this breccia is quite typical for the whole area over which the breccias have been found, excepting the occurrence on Fourmile Creek noted above. The cement is of a light-buff or pale-brown color, firm, but somewhat open and porous in texture, and this material, which is clearly a compacted ash, is thickly crowded with angular fragments of sedimentary rocks, chiefly of shales, but with mingled masses of limestone. These included pieces are generally small—not above an inch or two across—decreasing to microscopic dimensions. They do not appear to have suffered any metamorphism.

In general, the breccias remain as thin caps on the hills—as, for example, those through which Fivemile Creek cuts its way. These hills and the open country between Fourmile and Fivemile creeks attract attention by their peculiar appearance. Rock exposures are rare, and it is only along the bluff banks of the streams and on the steeper hillsides that the geologic structure is seen. The fragments forming the breccias fell upon a greatly eroded country, and the knobs and bowlder-like masses of quartzite and limestone that are occasionally seen are parts of this prevolcanic topography emerging through denudation from the cover of volcanic débris. In other places, where the breccias have filled old hollows, they are better preserved and are often of considerable thickness, as in Fivemile Canyon, where the stream has cut through them and they are seen penetrated by basic dikes. The farthest point to the southeast at which they have been seen is on lower Flagstaff Creek, where a few very small patches were found on the sides of the hills of Cambrian limestone.

The enormous amount and finely comminuted character of the fragments of the sedimentary rocks that they carry are of great interest, as they prove that violent explosions must have occurred to blow out so great a quantity of the stratified rocks which formed the foundation of the old volcano, and through which the former conduit of the lavas which succeeded these breccias, and upon which they have nearly everywhere been found to rest, must have passed. It should be also stated that these explosions appear to have been the first phase of external igneous activity, since the breccias, wherever found, are resting directly upon the old eroded land surface of sedimentary rocks, while the lavas rest upon the breccias. Nor have the breccias ever been found succeeding each other with any other material between; they belong exclusively to one period of eruption, and may, indeed, represent but one great and violent explosive outburst which cleared the way for the lava flows that succeeded, recalling in this respect some of those which have given rise to the Maaren in the Eifel district in eastern Germany.

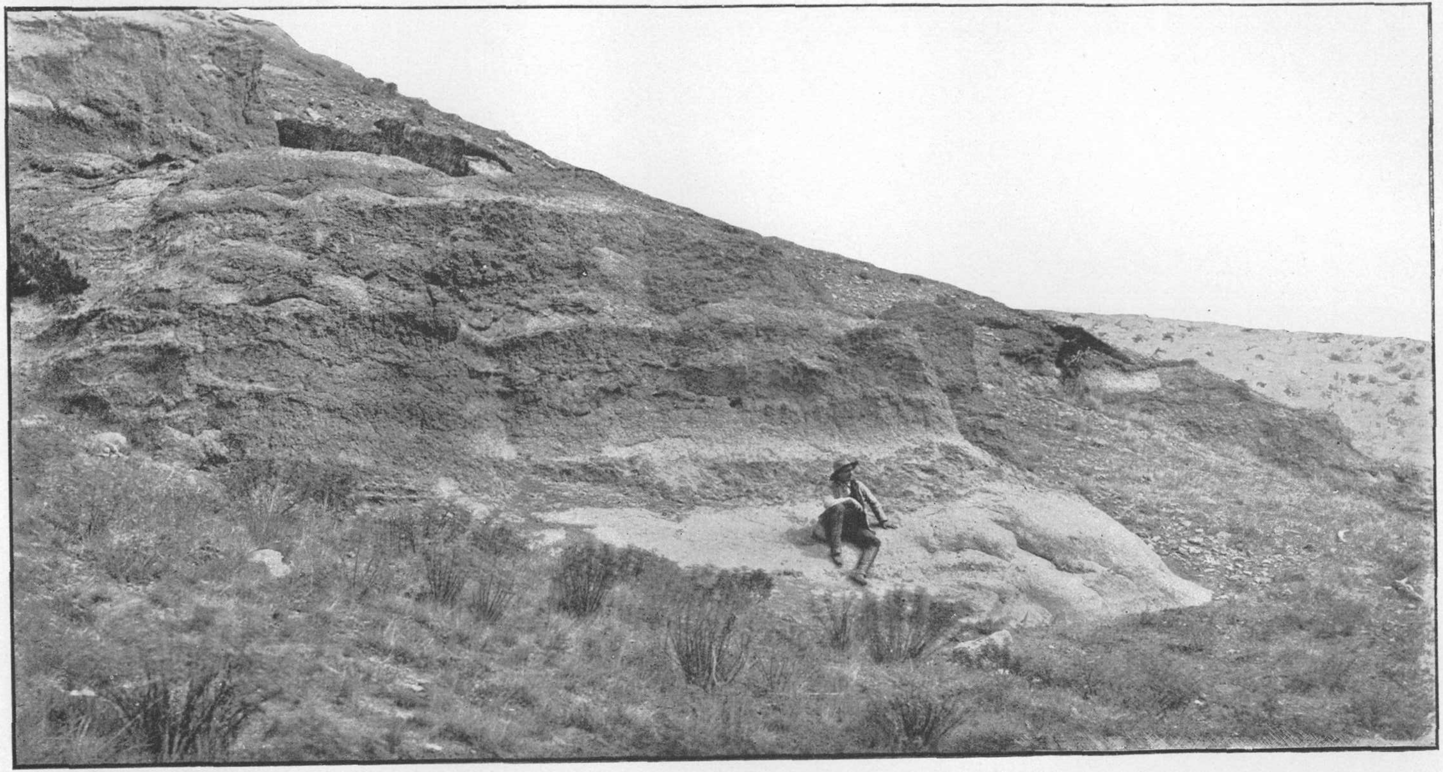
The tuff represents the lighter, finer, volcanic ash which succeeded the rain of heavier, coarser material which formed the breccias. The latter naturally grade into it, and as it is composed of light, incoherent particles it has suffered so greatly from degradation that but little of it remains, and actual outcrops are difficult to find. For reasons already given, it also grades into the lake beds and alluvium. In general, in a washed-down and transported condition, it is found in quantities as the soil, more or less mingled with other material and lying upon the other formations. This is shown by microscopic examination, which proves the material to be largely composed of fine, angular fragments of volcanic glass. Much of the area which is delimited upon the map is thus composed of mingled tuff and breccia in a degraded condition. Careful search, however, revealed the existence of a bed of tuff some 40 feet in thickness in an undisturbed condition, as it was originally piled up, the exposure being situated on the slopes west of the canyon of Checkerboard Creek. The outcrop shows an excellent exposure to the southwest, and a view of it is given in the accompanying illustration (Pl. XI). The face of the outcrop has smooth, rounded surfaces, which may be seen in the view, and these bear abundant evidences of rain-washing in little rill channels and pendulous portions and globules formed by the drying of drops of dirt-laden water. The consistency of the tuff is about that of a tough clay. A lens from 1 to 3 inches thick, holding quartzite, Mesozoic sandstone, and pebbles of volcanic rock, was noted in the exposure, but with this exception no pebbles were seen, and the character of the rocks is quite constant. It is of a pale-brown, earthy color, and microscopic examination shows that it is formed mostly of small glass shards, together with broken crystals and tiny bits of shale. The chemical analysis also, as shown in Chapter VI, allies it with rhyolite in chemical composition. By gradation in the deposits the mass shows that character of rude bedding commonly seen in accumulations of ash showers, and the beds dip at 5° to the northeast, and therefore away from Castle Mountain. The material rests upon breccias, and has itself been protected from erosion by glacial drift.

V. IGNEOUS ROCKS NOT OF CASTLE MOUNTAIN ORIGIN.

Besides those rock masses which by reason of their geologic position or their structural and chemical peculiarities can be referred without doubt to the Castle Mountain period of eruptive activity, there are, as previously mentioned, a few others whose origin is clearly different or in doubt. Since, however, they throw light on the geologic history of the district, they are worth a brief description at this point.

DIABASE.

This rock occurs on the southwest side of the great granite mass as a thick sheet intruded in Belt shales, and with them upturned against the mountain and folded up at that point. Wherever it has been seen it presents the same appearance and mode of occurrence, that of a



TUFF BEDS ON NORTH FLANK OF CASTLE MOUNTAIN.

heavy, black intruded sheet of trap, some 20 feet in thickness, lying conformably in the beds of the Belt formation and like them tilted and folded. Its conformability, its granularity, microstructure, and the alteration it has produced in the shales, all prove that it is an intrusive and not a surface flow. From these facts it is also evident that it is the oldest igneous rock in the district, antedating all others by a long period of geologic time. Its conformability and the intricate manner in which it is folded, at once negative the idea that it could have been contemporaneous with the Castle Mountain outbreak. Moreover, in other localities to the east and southeast, where the Belt formation is exposed over large areas, similar sheets of trap rock, consisting of a precisely similar diabase, are found intruded in them; they have been found near the canyon of Sixteenmile Creek, some 20 miles to the southeast.

It is therefore evident that while these beds were horizontal, and previous to the Mesozoic disturbances which folded them, there were extensive injections of trap sheets, on a much smaller scale, but in a similar manner to the intrusion of the trap in the Juratrias areas along the Atlantic border. Indeed, so strongly do the rocks themselves resemble the eastern Mesozoic diabases in their outward appearance, microstructure, and mineral composition, that specimens from different localities could not be distinguished. The rock possesses, wherever seen, a rhomboidal or platy parting, and a poor columnar structure was also observed in places. Weathered surfaces and those of the joint planes are of the rich brown color so often characteristic of this rock.

INTERBEDDED ASH DEPOSITS.

At a certain horizon in the series of Dakota sandstones, quartzites, and shales is found a rock of a very fine grain, conchoidal fracture, and of a dark-purple to a lavender color. Lithologically it differs entirely from any of the strata in which it occurs, but it is conformably interbedded in them wherever seen. Outcrops have been found in several widely separated localities: in the Cretaceous syncline area to the northeast of Blackhawk, where it is cut by one of the dikes previously described, in the Cretaceous shales in the basin of the creek east of Lower Bonanza, and in similar shales on the east branch of Willow Creek. In the field it was supposed that this was a fine-grained, intrusive rock, but a microscopic examination of thin sections showed at once that it was composed of clastic material, chiefly angular fragments of quartz and feldspar mixed in a cement composed largely of fragments of volcanic glass. These latter show the cusp-shaped forms so characteristic of the shards ejected in volcanic eruptions. The rock represents, therefore, a volcanic ash bed, and we thus have evidence of igneous activity in neighboring districts while these Mesozoic strata were being deposited. The conformability of the ash deposit points to its having been laid down in water in a manner similar to the shales and sandstones themselves, the latter beds both above and below being of precisely similar lithologic nature.

CRAZY MOUNTAIN TYPES OF ROCKS.

The wide, open valley of the South Branch of the Musselshell, cut in the soft Cretaceous strata, is everywhere penetrated and seamed by intruded sheets of igneous rocks accompanied by occasional dikes which are easily recognized in the field to be of Crazy Mountains types and origin. A number of these are shown on the map. Although topographically the Musselshell divides the Crazy Mountains area from that of Castle Mountain, geologically the separation is not perfect, since the same varied and extensive network of peculiar intrusive rocks which are characteristic of the Crazy Mountains is carried over into the foothills of Castle Mountain on the south. They consist of porphyrites, acmite trachytes, and the "theralite" of Rosenbusch, and have been described by Wolff.[1] Since a full description of these peculiar rocks, together with an account of the modes of occurrence, will appear in another publication of the Survey, on the Geology of the Crazy Mountains, the reader is there referred for a detailed account of them. That these rocks antedate the Castle Mountain period of eruption is clearly shown by a number of facts, one of the most evident being that a dike of acmite-trachyte, which has evidently been eroded, is covered by the great flow of rhyolite which extends down the slopes inclosed by the bend of Bonanza Creek. These sheets certainly occur to the north of Bonanza Creek in the Dakota sandstones which lie in the bottom of the synclinal trough, and this marks the greatest distance to which, in this direction, the Crazy Mountain intrusives have penetrated. These rocks have been kindly examined by Professor Wolff, who confirms the authors in their supposition as to their distinctive Crazy Mountain habit and mineral nature.

Besides those which are clearly types of Crazy Mountain rocks, there occur others near Bonanza Creek and between it and Flagstaff, which, partly from their mineral nature, but more on account of their decayed condition, must remain uncertain, whether they are of Crazy Mountain or of Castle Mountain origin.

In addition to those intruded sheets or masses whose direct connection with the main center can be either clearly seen or indirectly proved, there are several smaller masses of igneous rock occurring within the limits of the map. It is probable that to a certain degree they are contemporaneous in origin, and, although they occur in Paleozoic or pre-Paleozoic strata, were injected during the Tertiary disturbances

[1]Neues Jahrb. Min. 1885, Vol. I, p. 69; 1890, Vol. I, p. 192. Rosenbusch, Mass. Gest., 1887, p. 247. Petrog. Crazy Mountains, Montana: Northern Transcontinental Survey, 1885. Geol. Crazy Mountains: Bull. Geol. Soc. Amer., Vol. III, 1892, pp. 445-452. Acmite-trachyte Crazy Mountains, Wolff and Tarr: Bull. Mus. Comp. Zool. Harvard, Coll., Vol. XVI, No. 12, 1893.

which closed the long eras of subsidence in this region. By their mineral and chemical composition they are so closely related to the igneous rocks of Castle Mountain that no doubt can exist that the same deep-seated liquid reservoir furnished the material for both. One of these masses is that which forms the main portion and crest of Black Butte. The intrusion has occurred in Cambrian sandstones. Besides this mass there are several intruded sheets of porphyry of a similar nature in the immediate vicinity, as shown on the map. It is certain that there are several sheets at this point, and possibly they have been connected with a laccolitic intrusion of which Black Butte now presents an eroded remnant.

Similarly intruded masses occur in the Belt shales near the junction of Checkerboard Creek with the Musselshell. They are dense, tough, light-colored rocks—quartz-porphyries—and resist erosion well, so that where they occur they form hills, though it is probable that the topography depends also in part upon geological structure at these points. These masses have produced a contact metamorphism in the slates and argillaceous limestones of the Belt formation, but it is very local in character and confined to the immediate neighborhood of the igneous rock. Through one of these hills the Musselshell has cut down a very narrow canyon, giving excellent exposures of the igneous and sedimentary rocks, as noted by Messrs. Dana and Grinnell.[1]

[1] Report of a Reconnaissance from Carroll, Mont., to Yellowstone Park. U. S. War Dept., Washington, 1876, p. 113.

CHAPTER VI.

MICROSCOPICAL PETROGRAPHY.

With but very few exceptions, the igneous rocks of Castle Mountain present only well-known and well-characterized types. They are confined mainly to varieties of the granitic group, and from a structural point of view they offer all the different forms of crystallization that a highly siliceous magma can assume under the most varied physical conditions; they range from a medium-grained granite on the one hand to glassy pitchstone and tuffs on the other. In the idea of volume conveyed by the superficial areas of the rock masses these acid forms far outrank all of the other varieties in the district combined.

Associated with them, however, as has been pointed out in the preceding chapter, are basic rocks in much smaller amount, while rocks of intermediate character play but a subordinate rôle. The basic rocks are basalt and a few lamprophyric dikes, while those of intermediate composition are confined to a diorite approaching syenite and to porphyries at times inclining to porphyrites.

The petrographic study of the rocks of the district is therefore chiefly that of granite, granite-porphyry, quartz-porphyry, rhyolite, and rhyolitic pitchstones and tuffs.

CLASSIFICATION.

In the present unfortunate state of confusion regarding the classification of igneous rocks and the use of petrographic terminology, it is generally necessary for a writer to define exactly the sense in which his terms are used. It will probably be a matter of great difficulty to obtain in the future any international concordance on this subject, but it would seem as if the times were ripe—overripe, in fact—for entirely dropping at least distinctions in classification based on the geologic age of igneous rocks. A method which is of very little practical use and which can not fail to produce wrong impressions should certainly be dispensed with. It is and ought to be the privilege of science to free itself from the errors of the past rather than to drag them forward as an increasing load to its own impediment.

We notice with regret that Professor Zirkel, in the recent edition of his great work,[1] has been unable to free himself from tradition in this respect, and that, admitting the uselessness of this distinction for coarse-grained rocks, he still retains it for finer-grained porphyritic ones, a proceeding which, it seems to us, is lacking in logic. We can

[1] Lehrbuch der Petrographie, Leipzig, 1893, p. 838 et seq.

not agree with him when he claims that it should be retained on account of the useful purpose it serves in geology. If a distinction which was formerly based on erroneous conceptions should be retained for geologic purposes, why, we may ask, should the cut be made arbitrarily at the beginning of the Tertiary, or, indeed, why should we have but two sets of names for the same objects—why not three, four, or one for each geologic era, as proposed by Ébray? As in England, the distinction has never held sway in this country, owing largely to the writings of Dana, and it may now be held as certain that it never will, though at times one may notice a sporadic usage of terms in conformity with this idea. As Iddings has already indicated,[1] the original use of many of the most important terms that are used for paleo-igneous rocks, such as porphyry and porphyrite, was clearly a structural one, the idea of age being fastened upon them later. As all of the rocks in the Castle Mountain area, with but one exception, are Tertiary, it is evident that all terms in this work are used without reference to geologic age. So we have:

Granite, so coarsely granular that the component particles are readily seen by the eye alone. It is often porphyritic, and occurs in the central stock.

Quartz-porphyry, with groundmass so finely granular that the component particles can not be distinguished by the eye; occurs chiefly in the intruded sheets, and passes into

Rhyolite, which contains the partly crystallized glassy forms or those dense ones which only under the microscope reveal themselves to be holocrystalline, and forms almost exclusively the flow masses. The term granite-porphyry is also used for the transitional form between granite and quartz-porphyry, to designate the finely grained facies of the granite, which are often full of porphyritic feldspars.

In the same way the terms porphyry and porphyrite are used to designate porphyritic rocks of a holocrystalline, fine-grained texture, which in this district are found in intruded sheets and dikes, the former consisting mainly of alkali feldspars, the latter chiefly of lime-soda ones.

In thus using these terms without reference to geologic age, as has been previously done by several petrographers, and in confining them to certain structural forms generally, though not necessarily, occurring in sheets, dikes, and intrusions, we believe that a great advantage to petrographic terminology is gained; for if, for example, the terms rhyolite and quartz-porphyry are used only with strict reference to the geologic age of certain rock masses, we have then no intermediate term between granite on the one hand and glassy semilithoidal material on the other, since the terms quartz-porphyry and rhyolite are both required to cover all intermediate structural forms. While this is true in theory, yet, since among the older rocks the glassy to lithoidal forms

[1] The eruptive rocks of Electric Peak: Twelfth Ann. Rept. U. S. Geol. Survey, p. 582.

have been largely swept away by denudation or so changed by secondary processes of devitrification, etc., that they are largely indistinguishable from originally holocrystalline granular ones, it is a fact that practically these terms have been used also in a structural sense. It would therefore seem logical to drop the conception based on geologic age and let practice and theory combine. The term granite-porphyry has been used to partly cover this deficiency, but many writers, following Rosenbusch, are inclined to restrict its usage to a definite mode of geologic occurrence, and even if this restriction should be disregarded the structural sense in which it has been used would not cover the necessary ground.

As pointed out by Prof. J. D. Dana,[1] it is unfortunate that the word porphyry has been perverted from its original use as a purely structural term designating all kinds of porphyritic rocks, to become the name of a particular kind of rock. In the same way the use of the term granulite, which might so well be employed to designate all granular rocks which are not porphyritic, is prevented by its being the name of a rock of comparatively limited occurrence. Two such general terms, it would seem, are greatly needed in petrographic terminology, and it would be especially a great benefit if the term porphyry could be detached from its specific use and confined entirely to a general structural one.

ROCKS OF THE INTRUDED MASSES.

GRANITE.

This rock is found best and most typically developed in the southern portion of the great mountain mass, as at Elk Peak and above the town of Castle, and morainal bowlders of it fill the deep ravines of the various streams issuing from this side of the mountain. A hand specimen collected at Elk Peak appears at first glance to be an extremely coarse-grained rock of a mottled grayish-white color. A closer examination shows, however, that this coarse-grained appearance is due to the great number of feldspar crystals, about 1 centimeter long by about a half centimeter broad, which lie thickly crowded together in a much finer grained groundmass, whose grains average about 1 millimeter in diameter, and which would thus form by themselves a rather fine-grained granite. The large feldspar phenocrysts are seen to be Carlsbad twins. The ferro-magnesian minerals are biotite and hornblende. They form a considerable part of the finer-grained portion, giving it its grayish tone. They never attain such proportions as to rank, like the large feldspars, as phenocrysts in contradistinction to the medium-grained mass. From this type all gradations may be found to forms whose groundmass sinks to grains of microscopic dimensions, giving transitional varieties into granite-porphyry. These varieties, and that which comes under the head of granite-porphyry proper,

[1] Manual of Mineralogy and Petrography, 1887, p. 441.

form probably the larger part of the mountain mass and lie chiefly to the north and west. It is impossible to draw any lines between them either structurally or upon the map, and hence for convenience the term granite has been employed in a general geologic sense in the other portions of this bulletin, for the whole intruded stock.

The granite, and in general the whole rock mass throughout, is very miarolitic; that is, full of cavities of various sizes which have been produced by the contraction in volume incident to the cooling and crystallizing of a liquid mass. These cavities, while abundant, rarely reach great size, the largest observed being an inch or two long. They are thickly studded with free, projecting, outgrown crystals of quartz and feldspar. The latter, which at times reach a length of 1 centimeter, show the common habit of a combination of the prism with the positive and negative unit rhombohedrons ($10\bar{1}1$ and $01\bar{1}1$). The feldspars, which are much smaller, are white or pink in color, dull in luster as a rule, and developed tabular on the clinopinacoid. They are almost universally Carlsbad twins, presenting the simple forms *c* (001), *b* (010), *m* (110), and *x* ($\bar{1}01$). The plane *x* ($\bar{1}01$) having nearly the same inclination to the vertical axis as the base, the two in the twinned crystal lie nearly in one plane, as shown in the accompanying fig. 8.

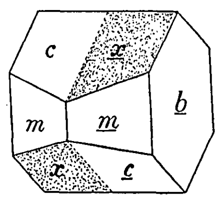


FIG. 8.—Orthoclase crystal from miarolitic cavity of granite.

The plane *x* ($\bar{1}01$) is much rougher than the basal plane, and the prism is extremely short. As the planes of the crystals are nearly always dull except the clinopinacoid, which is much striated by a vicinal prism face, no good measurements could be obtained on the goniometer. On one crystal the prism faces were measured as follows:[1]

$$m \wedge m\ (110 \wedge 1\bar{1}0)\ \text{meas. } 61^\circ\ 45',\ \text{calc. } 61^\circ\ 13'.$$

Not enough material for an analysis of these feldspars is at hand, but from a consideration of the bulk analysis of the rock, given later, it is probable that they are anorthoclase containing to some extent the albite molecule.

These miarolitic cavities are thus similar to those found in the well-known granite at Baveno, on the Lago Maggiore and in the granite porphyry of the Mourne Mountains in Ireland, though on a much smaller scale. No secondary minerals, such as zeolites or calcite, have been found on them, nor any of the ferro-magnesian group, though these are abundant in the rock itself. It seems quite probable that the well-crystallized condition of the minerals in the cavities is due to the mineralizing influence of water vapors at a high temperature, which, escaping from the cooling magma in which they had been held chemically combined under great pressure, would naturally collect in such cavities,

[1] Similar crystals have been described and figured by Kokscharow, Conf. Min. Russ., Vol. V, p. 125; Atlas Plate LXXIII, fig. 8.

thus producing those conditions which Daubrée has so successfully imitated in his well-known experiments. In this respect they are also similar to the conditions existing in lithophysæ, which contains similar minerals, as pointed out and described by Iddings and Penfield.[1]

Microscopically, in thin sections, the following minerals are disclosed: Iron ore, apatite, titanite, zircon, biotite, hornblende, oligoclase, orthoclase, and quartz, the constituents of a normal hornblende-biotite-granite. Their freshness or state of preservation varies, of course, with the individual specimens collected from different parts of the mass. The biotite has a very intense pleochoism between a pale ocher-yellow and a deep umber-brown; the hornblende is green with a tone of brown, also pleochroic, and with a medium angle of extinction. Both of these minerals are always idiomorphic; they are not abundant in the sections and have not been observed in intergrowths or in such relations that their relative ages could be determined. The oligoclase is generally quite fresh and striated in very fine lamellæ; the nearly parallel extinction to the twinning plane in all cases indicates an acid oligoclase, as might naturally be expected from the composition of the rock. The orthoclase or nonstriated feldspar is never fresh with the sanidine habit, but cloudy from incipient kaolinization, like those of the older granular rocks. Microcline has never been observed in any of the sections; a natural result of the unpressed condition of the rock. The quartz shows no undulatory extinction and is clear, but contains many inclusions, both liquid and gaseous. Glass inclusions are also common, often of dihexahedral form and having a fixed bubble. The apatite, titanite, and zircon are not common and present nothing of especial interest.

An analysis of the freshest material which could be obtained at Elk Peak was made, with the following results:

Analysis of granite from Elk Peak.

[By L. V. Pirsson.]

	Per cent.
SiO_2	72.48
TiO_2	.32
Al_2O_3	13.14
Fe_2O_3	1.66
FeO	1.02
MnO	Trace.
MgO	.15
CaO	1.04
Na_2O	4.22
K_2O	4.88
Li_2O	Trace.
H_2O (ign)	.42
Total	99.33
Sp. gr	2.62

[1] Iddings, Obsidian Cliff: Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 279. Iddings and Penfield: Am. Jour. Sci., Vol. XLII, 1891, p. 39.

This is in all respects the analysis of a normal granite, and the amount of loss on ignition shows that the rock is comparatively fresh. The relative amounts of soda and potash are to be noted; it is probable that the unstriated feldspar contains the albite molecule to some extent.

It is, however, in its structure, the normal type of which is shown in fig. 1, Pl. XV, that the rock presents the points of greatest interest. As noted megascopically, it possesses a medium degree of granularity for a granite, but the structure is not always entirely the hypidiomorphic one of the majority of granites. The quartz has a certain tendency to assume idiomorphic outlines; against orthoclase an occasional angular contact between the two is seen, the quartz possessing the salient angle; at other times it penetrates the feldspar in broad tongues or lies against it in a rounded grain. It is also observable in this coarse-grained form that one finds places where several of these quartz areas are oriented similarly and extinguish simultaneously between crossed nicols. Sometimes they are connected by an intervening strip of quartz, and these are often surrounded by a singly polarizing plate of feldspar. Thus there is a rude approximation to graphic granite in the arrangement of these parts.

These phenomena, together with the presence of the glass inclusions in the quartz, all point to the younger nature of the granite, and show that it has crystallized under somewhat different physical conditions from most of the older coarse-grained rocks. The age of the feldspar phenocrysts can not be assigned to one particular period. They contain the older minerals, while included quartz grains prove that they were growing amongst the latest components of the rock. The fact of their existence in it does not make the rock any less a granite, since this is determined by the comparative coarseness and structure of the groundmass. It may confidently be expected that as research is more extended the occurrence of such porphyritic granites will be found to be more common. An extremely coarse-grained granite with huge phenocrysts of feldspar has been described by one of the writers,[1] while a number of occurrences are mentioned by Zirkel[2] in his recent comprehensive work.

GRANITE-PORPHYRY.

The minerals that have been described as forming the granite remain the same in species and relative abundance throughout the whole mass, but their relative dimensions change, giving rise to variations in structure, as previously stated. The feldspar phenocrysts show the least variation, the change being most marked in the groundmass surrounding them. From a coarseness of grain which renders it a true granite, the grain becomes less and less coarse, until over large

[1] Am. Jour. Sci., Vol. XLVI, 1893, p. 363.
[2] Lehrbuch der Petrographie, 2d ed., Vol. II, 1894, p. 17.

areas it becomes so fine that the individual components can no longer be differentiated by the eye alone, and the rock thus passes into a granite-porphyry. Under the microscope, this change is observed to progress in two directions. In the first the grains simply become smaller, retaining the irregular hypidiomorphic structure characteristic of granites, though occasionally the quartz and feldspar show a tendency to assume that structure which Williams[1] aptly characterized by the term micropoikilitic. Quartz also assumes the position of a common phenocryst, a phase not seen in the granite. In the other direction the groundmass assumes that form of regularly oriented intergrowths of quartz and feldspar seen in graphic granite and commonly called micropegmatite.

GRANITE-PORPHYRY WITH MICROPEGMATITIC GROUNDMASS.

This form is most common in the northern and western portions of the mass. All gradations between it and the granite may be found. The tendency noticed in the granite for several grains of quartz to be similarly oriented increases at times till a granite of a rather fine grain, but of micropegmatitic structure, as shown in fig. 6, Pl. XII, is formed, and this passes by transitional forms into a true granite-porphyry with this structure of groundmass. The micropegmatite occurs not only in fringes bordering the feldspars, but in distinct, independent areas freely scattered through the groundmass.

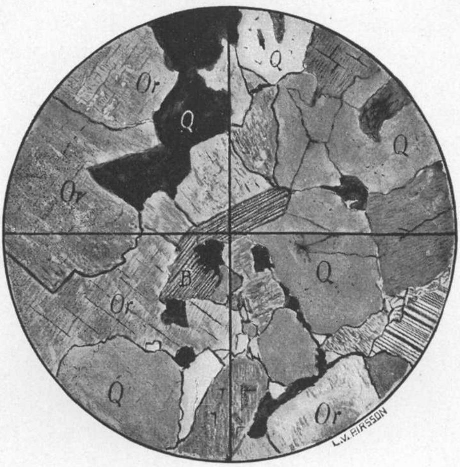
The dark-colored minerals in these occurrences of granite-porphyry are extremely apt to be altered, the biotite to chlorite, white mica, etc.; the hornblende to chlorite, calcite, limonite, serpentine, etc.

Secondary origin of micropegmatitic structure.—Some petrographers have been inclined to regard a micropegmatitic structure as being at times of secondary origin. Thus Irving[2] was disposed so to regard it in certain granite-porphyries of the Lake Superior district; quite recently Hobbs[3] has attributed its formation in a clastic rock studied by him to metamorphic origin; while Romberg[4] considers the structure to be due to corrosive silica-bearing solutions acting on the feldspar of igneous rocks.

That the structure is at least generally of primary origin—that is, formed by crystallization from a molten igneous magma—is not disputed, its occurrence in recent unaltered rhyolites, as in the beautifully fresh material from Obsidian Cliff described and figured by Iddings,[5] being sufficient evidence upon this point.

Examined critically, the reasons given by the authors mentioned for regarding the structure as of secondary origin in the rocks studied by

[1] Jour. of Geol., Chicago, Vol. I, 1893, p. 176.
[2] Copper-bearing rocks of Lake Superior: Mon. U. S. Geol. Survey, Vol. V, 1883, p. 114.
[3] Bull. Geol. Soc. America, Vol. IV, 1893, p. 171.
[4] N. Jahrb. Min., Bei.-Bd. VIII, 1892, pp. 314–374.
[5] Seventh Ann. Rept. U. S. Geol. Survey, 1885–86, p. 274.



a

b

a.—CASTLE MOUNTAIN GRANITE FROM ELK PEAK.

Q = quartz, Or = orthoclase, B = biotite. Actual field 4 millimeters diameter. From a micro-drawing in polarized light; crossed nicols.

b.—CASTLE MOUNTAIN GRANITE-PORPHYRY.

The white areas quartz, the dark feldspar. Very coarse-grained micro-pegmatite passing into granitoid structure. Actual field 4 millimeters diameter. From a micro-drawing; crossed nicols.

them, resolve into these: that it was so believed by them because of its appearance, and also because, outside of the micropegmatite groups, there were areas of quartz held to be secondary which had the same orientation as that composing them. The whole is therefore presumably believed to be quartz deposited from silica-bearing solutions which had corroded the feldspar. We must imagine, therefore, a feldspar crystal acted upon by solutions which, eating into it, create long, narrow, bent, broken, or sinuous canals in all directions, and these canals filled with deposited quartz which preserves the same orientation throughout. When we reflect upon the manner in which cavities are filled by undoubted quartz of deposition, such a process does not seem very probable.

As to the secondary quartz outside of the group which has a similar orientation, it would be quite natural that silica-charged solutions, coming in contact with those portions of the original micrographic pegs which reach the surface, would be influenced by them and deposit quartz with a similar orientation. This is in perfect analogy with secondary quartz deposited around the detrital grains of quartzites and sandstones.

The fact that it occurs at times associated with altered and weathered feldspar can not be adduced as a proof of the secondary nature of this structure. If it were original and exposed to alteration the feldspar must decay, be changed to kaolin or sericite, but evidently the quartz can not alter. On the other hand, by the pressure exerted in orogenic forces, feldspar crystals might crack through and through in various directions, and especially along cleavage planes. By the action of capillary forces silica-charged solutions might be drawn into the cracks and quartz deposited, and in this way a secondary structure be formed which might resemble a micropegmatitic intergrowth.

While, therefore, by no means denying the possibility that this structure may at times be a secondary one, the authors desire to point out that those facts which have been adduced as proofs of its secondary origin are not in themselves conclusive, that until more positive proofs are added it must still be generally held to be of igneous origin, and that great caution should be used in pronouncing it to be secondary.

INCLUDED MASSES IN THE GRANITE.

These have been mentioned in the preceding chapter, and their mode of occurrence has been described. On the whole, they appear to be somewhat darker and richer in ferro-magnesian minerals than the main granite. At times they are of finer grain, at others coarser, than the inclosing rock. They are also less porphyritic, and sometimes entirely free from phenocrysts, presenting the appearance of a fine-grained granite.

An analysis of a specimen of this latter variety from the broken-down rock masses on the ridge at the extreme head of Cottonwood Creek gave the following results:

Analysis of mass included in granite.

[By L. V. Pirsson.]

	Per cent.
SiO_2	61.87
TiO_2	.87
Al_2O_3	17.26
Fe_2O_3	2.35
FeO	2.43
MnO	.03
MgO	1.82
CaO	3.23
Na_2O	5.18
K_2O	3.83
P_2O_5	Trace.
H_2O (ign)	1.07
Total	99.94
Sp. gr.	2.67

This analysis is essentially that of a syenite somewhat rich in lime, iron, and magnesia, and thereby a transition toward diorite. Under the microscope the rock is found to consist of a hypidiomorphic mixture of biotite, hornblende, apatite, iron ore, orthoclase, plagioclase, and quartz. The ferromagnesian components are moderately abundant; orthoclase is by far the most common mineral, while of quartz there is little and that mostly interstitial. The rock is, in fact, a fine-grained hornblende-mica-syenite.

Sections cut from the finer-textured and somewhat porphyritic forms show the same minerals and structure, though at times small areas of quartz and feldspar in micropegmatitic intergrowths are seen. The essential variation seems to be in the amount of quartz, and thereby in the silica in the magma, though there is also a relatively small gain in lime, iron, and magnesia in the variety analyzed.

At other times the included masses seem practically the same in nearly all respects as the inclosing granite or granite-porphyry, and differentiated from it only by a somewhat denser texture and a spheroidal parting suggesting the arrangement of the scales of an onion, a peculiarity which renders this variety of rock quite noticeable.

The authors are inclined to attribute the formation of such bodies to a liquation of the liquid magma, a process which produced masses somewhat richer in basic oxides, and, as the temperature gradually fell and the cooling magma stiffened and became more viscous, were no longer miscible with the main portion, producing, in fact, a sort of emulsion of the two on a vast scale. Each portion then crystallized in place. This is similar to the theory which Bäckstrom[1] has lately advanced for the origin of orbicular granites, and it seems to us that the large included masses which differ somewhat from the inclosing rock, the spheroids of orbicular granites, and those agglomerated masses of the dark ferromagnesian minerals so commonly occurring in acid rocks ("schlieren" of the Germans) are all to be attributed primarily to the same cause, while their variation in composition, structure, and texture in different occurrences is to be explained partly by a greater or less continuation of the process and partly by the different physical conditions under which they have cooled and crystallized.

It should be noted, also, that these "schlieren" or agglomerations, rich in the dark ferromagnesian minerals, have nowhere been observed in the Castle Mountain mass.

DIORITE.

This is the predominant rock of the smaller mass occurring on the eastern slope of Castle Mountain, between Blackhawk and Robinson. The material constituting the central portion of the stock, as exposed in various prospect shafts, is a rather coarse granular rock of a very dark-gray color and quite even grain. The main component is seen to be feldspar, occurring with grains of augite and plates of a black glittering mica. The component particles range from one to several millimeters in diameter.

Under the microscope, in thin sections, the rock is seen to possess a granitoid structure and to be composed of the following minerals, named in the order of their crystallization: Iron ore, apatite, and zircon, followed by biotite, hypersthene, diallage, oligoclase and orthoclase, and quartz. The iron ore is moderately common in small grains. Apatite is generally diffused but not abundant. Zircon has been found in several good-sized crystals; the smaller microlites of this mineral seem nearly wanting. The biotite nearly always surrounds iron ore, is very strongly pleochroic, and of a rich umber-brown color.

The hypersthene is probably iron poor, as it has but a very pale, scarcely perceptible, pleochroism and has always a very low, double refraction, scarcely equal to quartz. This, with its parallel extinction, contrasts it sharply with the monoclinic augite, which has all the characteristics of diallage with parting parallel to (100). It is full of inclusions of the older constituents. Parallel intergrowths of the two pyroxenes have been observed in several cases, the same cleavage running through both; they appear to be joined on the front pinacoid (100). In these intergrowths the two varieties are differentiated in plain light by the pleochroism of the hypersthene, which seems, perhaps by contrast, to be more pleochroic here than elsewhere, and in polarized light by the difference in optical relations. The monoclinic augite is at times surrounded by small quantities of shreds of green

[1] Geol. Fören. i. Stockholm, Förhandl., Bd. 16, 1894, p. 128.

hornblende. All of these ferro-magnesian minerals tend to group themselves around the ore grains. It is evident that the period of growth of the augite overlapped that of the biotite, since the latter at times incloses it in grains. In the great majority of cases the striated feldspar present is an acid oligoclase, as is indicated by the almost uniformly small angle of extinction shown by lamellæ twinned according to the albite law in sections perpendicular to 010, and the nearly coincident extinction in individuals twinned according to the Carlsbad law. The same method shows that much more rarely an andesine with maximum extinction angles of 22° in this zone is also present. These determinations are according to the beautiful optical methods recently perfected by Michel-Lévy[1]. The twinning striæ are generally very fine. The crystals are in broad tables and fairly idiomorphic, recalling the plagioclase of basic granites, while the spaces between them are filled with orthoclase. Plagioclase is the most abundant mineral, closely followed by orthoclase. Quartz is rarely seen filling minute interspaces, but is evidently an original mineral.

An analysis, made of very fresh material, gave:

Analysis of augite-mica-diorite from Robinson.

[By L. V. Pirsson.]

	Per cent.
SiO_2	56.80
TiO_2	.46
Al_2O_3	18.30
Fe_2O_3	1.64
FeO	5.58
MnO	Trace.
MgO	3.63
CaO	5.31
BaO	.05
Na_2O	4.35
K_2O	3.28
Li_2O	Trace.
H_2O	.53
P_2O_5	Trace.
Total	99.93
Sp. gr	2.83

The high percentage of alkali is noticeable, and it must be inferred that the plagioclase can not be a lime-rich one. The analysis approximates that of a basic syenite—several analyses of rocks quoted as syenites could indeed be given which are extremely similar—but plagioclase is the dominant mineral, and the dark-colored components are those which recall certain gabbros; they are, indeed, in habit and

[1] Détermination des feldspaths, Paris, 1894, Baudry et Cie.

appearance, extremely similar to gabbro rocks collected in southern Montana near the National Park.

The rock under discussion may then be classed as an augite-mica-diorite which has a tendency toward the syenites in type.

From this type, as one leaves the center of the mass and proceeds toward the periphery, the rock becomes gradually lighter in color. Studied under the microscope, this change is found to consist in an increase in quartz; the hypersthene disappears, and the pyroxene occurs in smaller amount and is often intergrown with a green hornblende with a brownish tone of color, whose presence may be due to a paramorphic change in the augite. A good example of this variety is found in the rock cutting made above Robinson in building the highroad to Blackhawk. Mica becomes more prominent and the rock passes into a hornblende-mica-quartz-diorite. This is the type found in the hill back (southwest) of Blackhawk. On the western rim of the mass the rock has this composition, but is porphyritic; the feldspar phenocrysts are idiomorphic, and megascopically the rock strongly resembles the granite already described. This resemblance is heightened by the fact that it weathers into crags, as noted in the preceding chapter, which, seen from a distance, lead at first to an impression of the eastward extension of the granite to this point.

Under the microscope, however, the phenocrysts are seen to be a striated plagioclase similar to that found elsewhere. They are very abundant, and their interstices are filled with a granular mixture of mica, hornblende, orthoclase, and quartz, giving a transition form into quartz-diorite-porphyrite. No varieties with formation of a micropegmatitic intergrowth of quartz and feldspar have been observed in connection with the diorite.

The southern portion of the mass which abuts against the Cretaceous strata forms a high ridge with castellated crags, similar to the high hills back of Blackhawk, just described. The rock constituting these outcrops is, however, of a different character from the main mass. It is a most typical granite-porphyry, with phenocrysts of orthoclase, biotite, and quartz lying in a granular allotriomorphic mixture of quartz and feldspar. In the hand specimen it is of a pale-gray color with a fine granular groundmass in which feldspar and occasionally quartz phenocrysts are seen. In places among the outcrops inclusions of a darker, more basic character appear which bear the same relation to the inclosing rock as those already described as occurring in the granite. It is possible that this granite-porphyry is not a peripheral facies of the diorite mass, but a dike, an offshoot from the granite cutting along its boundary. The nature of the exposures is not such as to definitely settle this point, but, so far as can be judged, we believe it to be an integral portion of the diorite mass, and its granitic character to be due to a local differentiation in place in the cooling fluid magma.

CONTACT METAMORPHISM.

Contact metamorphism naturally divides itself into two classes: endomorphic, or the variation in crystalline structure and texture from the normal type which an igneous fluid mass assumes on cooling, due to local variations of the physical conditions produced by the adjacent rock masses; and exomorphic, those changes induced in the adjacent rock masses, such as baking, recrystallization, and the formation of new mineral compounds by the heat, aqueous vapor, and other gases at high tension given off from the cooling injected fluid.

Endomorphic in the granite.—Approaching the contact with the adjacent sedimentaries, the granite becomes finer-grained and porphyritic, passing rapidly into a granite-porphyry. Usually the area of contact is eroded, so that good exposures are not numerous for purposes of study. So far as observed there are no phenomena which are of especial interest or which have not already been frequently described by various petrographers. One of the most interesting and instructive examples of endomorphic contact metamorphism afforded by the granite is that which may be seen in the excellent exposure on Fourmile Creek, already described, where the granite abuts against the ends of the sedimentary beds and passes out between them in intruded sheets. Within a distance of 20 feet it passes from granite through transitional stages into granite-porphyry and into typical quartz porphyry in the intruded sheet. As seen in thin section, the granite at this point is rather fine-grained and porphyritic; the quartz of the groundmass has the tendency already noted to assume idiomorphic form; indeed, the rock might be well described as an extremely coarse-grained granite-porphyry in which iron ore and biotite are the only dark minerals and the feldspar is somewhat kaolinized. In the next stage, passing outward at a distance of about 6 feet, or nearly 2 meters, from the margin, the grain is perceptibly finer; the quartz grains are now rounded and the structure is that often seen in aplitic granites, where each component tends to assume its own form, a structure called by Rosenbusch panidiomorphic. In the next stage this process continues, and at times the quartz is observed in micropegmatitic structures with the feldspar. The change into the quartz-porphyry of the intruded sheet occurs suddenly, the groundmass sinking into a fine-grained allotriomorphic mixture of quartz and feldspar, while the phenocrysts remain of nearly the same size but are much fewer in number. This form is megascopically dense, with conchoidal fracture. The fine-grained quartz and feldspar of the groundmass are often observed in areas with micropoikilitic structure.

Quite similar transitions from granite to quartz-porphyry on the periphery of an intruded mass have been described by Hague,[1] with

[1] Geology of the Eureka district, Nevada: Mon. U. S. Geol. Survey, Vol. XX, p. 225, Washington, 1892.

petrographical details by Iddings,[1] as occurring in the Eureka district, Nevada.

Endomorphic in the diorite.—The diorite also suffers a very similar change at the contact. It grows finer in grain and more porphyritic, and at the actual contact is generally dense and aphanitic. Seen in thin sections this latter form is, however, holocrystalline, and consists of quartz and feldspar in characteristic micropoikilitic structure, embedded in which are plagioclase phenocrysts. The rock seems to be peculiarly liable to decomposition at the contact, and this holds true for the granite as well as for the diorite. So in the form just described the plagioclase phenocrysts are full of fine leaves of white mica similarly oriented along the cleavage lines, while the biotite which was formerly present is entirely gone, only chlorite remaining in its place.

At other times the diorite is observed retaining its full size of grain up to the very edge of the contact. This was especially noticed in material thrown out from a prospect shaft sunk on the contact with the Cambrian limestone a few rods east of the wagon road from Blackhawk to Castle, about one-half mile below Blackhawk, and on the knoll dividing two head branches of Bonanza Creek. The shaft is locally known as the "Frenchman's Claim." The material developed here is very fresh. The dark-gray diorite is seen sharply differentiated from the limestone, which is here white calcite, due to exomorphic processes.

Exomorphic changes.—In the example last mentioned there is a distinct band, about 1 inch in width, into which the substance of the diorite seems to have entered. It is a mixture of calcite with the dark minerals of the diorite—hornblende, biotite, and pyroxene mixed with calcite. As previously stated, it is sharply defined, however, from the diorite itself. Beyond this band occurs the metamorphic rock proper, which is a limestone changed chiefly into crystalline calcite, but filled with nests, pockets, and agglomerations of contact minerals. A pale oil-green grossularite garnet occurs in grains and in ill-defined crystals often lumped into masses, and rarely in well-defined dodecahedrons an inch in diameter. Associated with the garnet are masses of a brown vesuvianite, which was not found in good crystals. A green pyroxene is also common at times in well-defined crystals, and this occurs so abundantly in places that a mixture of it and calcite forms rock masses a few feet across. A phlogopite of a pale greenish-white color is also abundant, scattered through the rock. A more detailed description of the occurrence of these and other minerals is given in the last chapter of this bulletin. This calcite rock, with the garnets and vesuvianite scattered through it, strongly recalls the similar contact rock from Cuautla, State of Morelos, Mexico.

In the village of Blackhawk, where the limestone has been metamorphosed not only by the diorite but also by intrusive dikes and sheets, which have greatly intensified the effect, it has been changed into

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[1] Ibid., p. 342.

marble over large areas. At times the calcite composing the marble has cleavage surfaces nearly an inch across in the vicinity of the intrusive masses. The same is true also around the town of Robinson, but here the garnet, vesuvianite, and the other minerals mentioned above have not been seen. It is in these areas that the sulphides and other ores described in the chapter on the mining resources of the district have been chiefly deposited.

The effect of contact metamorphism on the shales has been to change them, in those localities where the action is the most marked, into tough, hornstone-like rocks. Under the microscope these shales appear as a cryptocrystalline mass. The section has a nearly uniform gray "pepper-and-salt" appearance; it is extremely difficult to identify with certainty individual minerals, but the mass evidently consists largely of quartz, feldspar, white mica, etc. This appearance is not greatly changed by the metamorphism, but the texture is much denser, so that the rock has a true hornstone-like appearance with a splintery fracture. In many cases, however, there are seams running through the altered rock, filled with green epidote in small grains and crystals. In some cases layers richer in lime have been altered, and immediately garnet and pyroxene appear with the epidote.

Near the contact locality on upper Fourmile Creek, described on page 60, a rock was collected, from the talus of the lower mountain side, which in the hand specimen appears to be a breccia of light-colored angular fragments cemented by a dark-colored material. Under the microscope the light-colored portions appear like altered shales, and show a cryptocrystalline to microcrystalline mixture of fine particles with larger angular fragments of quartz scattered through them, mingled with areas of coarser quartz particles. A banding in the finer-grained portions reveals the original planes of sedimentation. The pieces composing the breccia lie with the sedimentation planes at all angles. The dark-colored material cementing them consists of tourmaline mixed with quartz, which runs in bands, veins, and stringers through the rock. It is in irregular shreds and patches of a grayish-brown color, highly pleochroic. The occurrence of this rock near the contact is of interest, as it shows the formation of a contact breccia, and that the upward movement of the magma to the position where it now rests as a crystalline mass was attended with great force, shattering and rupturing the rocks along the plane of contact—a fact which will be subsequently noticed in the description of the effusive masses. The occurrence of the tourmaline is also of interest in evincing the presence of boric acid among the fumarole products of the cooling magma, and also in throwing light on the formation of a tourmaline-quartz-porphyry, to be described later.

The Cretaceous shales, which have been altered by the intrusion of the granite, are well exposed at the head of Alibaugh Creek. They are dense, black, tough hornstones, and by the eye alone are not to be distinguished lithologically from altered varieties of the Belt slates. In thin section, however, they disclose some marked differences, being characterized by the occurrence of andalusite, which has nowhere been observed in the altered Belt rocks.

The section shows the usual fine-grained mixture of clastic minerals, chiefly quartz, which is so characteristic of this class of rocks. Scattered through this are knots or ovoid spots, about one-half millimeter in diameter, which catch the eye, as they are much lighter in color than the mass in which they lie. This is due to the absence, or the local concentration into a few larger grains, of the dusty, sooty, organic matter which is elsewhere present, and also to the somewhat coarser crystallization of the component mineral particles. The rocks also contain irregular shreds of a brown mica similar to that usually found in contact hornstones. Scattered around among these knots are crystals of andalusite which attain an extreme diameter of 1 millimeter. They are bounded by the prism faces and the basal pinacoids, and with one exception show clear crystal outlines; the prism angles are wanting and their place is supplied by a narrowing wedge of included matter, which gradually tapers to a mere point as the center of the crystal is reached. At this point the four wedges come together, and the whole result is such that a basal section of the crystal shows for the clear andalusite substance the exact outline of a Maltese cross. This is, of course, only another variation of the chiastolite variety of andalusite. The mineral was proved by its optical characters.

The presence of this andalusite schist is of interest, as so few rocks of this nature have been described in this country, and recalls the well-known German occurrences which have become classic from the work of Rosenbusch.

ROCKS OF THE INTRUDED SHEETS AND DIKES.

APLITIC GRANITE.

This occurs in the form of very narrow dikes, rare in the granite mass, but common in the diorite; and where good exposures were seen the latter rock was generally penetrated by dikes of this rock. An excellent example was obtained from the material thrown out of the prospect shaft on the open hillside between Blackhawk and Robinson, the same locality from which the freshest and most typical diorite was obtained, whose description and analysis are given on page 89. Hand specimens show a grayish rock of a very fine grain, in which are seen occasional black plates of biotite. Under the microscope it is found to be a fine-grained, allotriomorphic mixture of quartz and unstriated feldspar; some plagioclase is present in idiomorphic crystals. From this phase it varies, becoming still finer grained, while phenocrysts of quartz and feldspar appear, and a transition into granite-porphyry occurs.

An analysis of a typical specimen gave the following result:

Analysis of aplitic granite.

[By L. V. Pirsson.]

	Per cent.
SiO_2	72.88
TiO_2	.45
Al_2O_3	12.90
Fe_2O_3	.74
FeO	1.05
MgO	.75
MnO	.05
CaO	.81
Na_2O	3.72
K_2O	5.03
H_2O	1.22
Total	99.60
Sp. gr	2.64

The very close analogy between this analysis and that of the granite is quite striking when we consider the origin of these dikes and the source of their supply.

It is interesting to note that along the wall and close to the contact they often contain large, irregular fragments of feldspar and of biotite, which have evidently been torn off from the inclosing rock and floated out in the magma in much the same way as the large crystals that are found in the well-known minette dike near Aschaffenburg, in Germany, though on a much more minute scale. Sections cut from the contact line and showing both the aplite and diorite indicate that the latter rock has suffered alteration along the contact plane. The large feldspars are altered, with formation of a considerable amount of sericite; the augites are changed into masses of carbonates, chlorites, etc., while biotite has changed to chlorite, earthy iron ores, rutile needles, etc. The most interesting change is that exhibited by the ilmenite or titanic iron ore. This is surrounded in places by leucoxene-like material, which occurs also in isolated masses free from the ore. This leucoxene is not, however, titanite, as is generally the case. It is composed of a yellowish-brown mineral, of extremely high single and high double refraction, which possesses cleavages intersecting at a right angle, and is uniaxial and negative. Such a combination of characters could belong only to anatase. That leucoxene is sometimes composed of anatase was maintained by Rosenbusch[1] and by Diller.[2] The present occurrence confirms this, but in the diorite here described the mineral does not occur in sharply defined crystals, but in crystalline masses and aggregates. It is not intended, of course, to assert that the changes in the diorite described above are due to contact action alone.

[1] Mikr. Phys., 1885, p. 332.

[2] N. Jahrb. Min., 1883, I, p. 192.

QUARTZ-PORPHYRY.

Introductory.—The quartz-porphyries are found chiefly as intruded sheets and masses around the eastern flanks of the mountain, where, as has been previously shown, they stand in direct genetic relationship to the granitic stock. In the study of a great number of intruded sheets and dikes it has been observed that transitions exist from the most typical of quartz-porphyries, with abundant quartz phenocrysts and quartzose groundmasses, into those where the quartz as a phenocryst is lacking but is abundantly found in the groundmass, on into varieties where quartz practically or nearly disappears, the feldspars assuming a lath shape and the structure a trachytic habit. Thus the range extends from quartz-porphyry into quartzless or syenite porphyry. These forms of transition are also expressed in the change in the chemical composition of the magmas forming these bodies, but it is to be noted that this change is not due alone to a simple sinking of the silica percentage and a corresponding rise of alumina and alkalies, but as the silica decreases there is also a corresponding rise in lime, magnesia, and iron, and this expresses itself by an increase in plagioclase and the ferromagnesian minerals, so that the eventual porphyries have strong tendencies to porphyrites. One or two occurrences, indeed, have all the habit and appearance of porphyrites, but unfortunately their greatly altered condition prevents satisfactory conclusions from either microscopic study or chemical analysis.

If, on the other hand, we disregard the geologic occurrence of the rock masses of the district and compare types of the acid rocks, both effusive and intrusive, from a structural point of view, all gradations will be found to exist. While the intrusive acid rocks are always holocrystalline, careful study with high powers of the microscope not revealing any interstitial glass base, yet they descend to types of exceeding fineness of grain. The effusive forms, on the other hand, pass from pure glassy pitchstone into semiglassy, microspherulitic types, and from these into microcrystalline groundmasses, and so on into granular crystalline forms in no wise distinguishable from the intrusive rocks and often possessing a higher degree of granularity than many of them. And these gradations are found not only in the extrusive bodies as a whole, but, as will be shown more in detail in a subsequent place, in a single, individual, continuous rock mass. The question of their degree of crystallization or granularity is not, therefore, one of geologic occurrence, but of physical condition, and while it is true that, in general, similar geologic positions cause similar physical conditions, and therefore similar types of structure, it is evident that this is not always the case and that the number of exceptions will multiply in ratio with the increase of geologic research. Castle Mountain furnishes a number of excellent and instructive examples of these exceptions. Since, however, it has been found convenient for purposes of description to divide the igneous rocks of the Castle Mountain district into three classes according to their mode of geologic occurrence, the quartz-porphyries described in the following section are those of the intruded sheets and dikes, while the effusive types will be treated later as transitional forms of the rhyolite. According to their distribution they may be divided into two main and separate occurrences—those of Castle Mountain proper, where as sheets and dikes they form peripheral fringes of the granitic stock, and the separate area of the North Fork of the Musselshell River.

Quartz-porphyry of Castle Mountain.—These rocks are generally dense, felsitic-looking, and of various shades of light colors, pale-gray, white, lavender, and brown being common. They break with a conchoidal or splintery fracture, and on fresh surfaces the lustrous cleavage of feldspar phenocrysts is seen. These feldspars are small and rather numerous, but generally not thickly crowded. The quartz phenocrysts often break out of the felsitic matrix of the groundmass and then show the common dihexahedral form, the angles and planes roughened and rounded, never sharp and lustrous like the quartzes of veins and geodes. The rocks are much jointed, and their sharp angular blocks form great talus slides which cover the mountain slopes of the upper valleys of Fourmile and the other creeks draining the eastern half of the mountain.

Microscopically these rocks are seen to possess a monotonous regularity and simplicity of structure and mineral composition. They are of a type which is extremely common wherever such rocks are found, and which has often been described by various investigators. Only such details are therefore given as will enable one to recognize the types. The phenocrysts are quartz, feldspar, and biotite. The quartz shows the common phenomena of cracking and of deep embayments filled with groundmass. It contains fluid and glass inclusions, often as negative crystals. The feldspar phenocrysts are of plagioclase and an untwinned feldspar, the latter at times singly twinned according to the Carlsbad law. The bulk analysis of a typical example shows a large amount of soda present, as indeed do all of the acid rocks of the district, so that it must be concluded that the albite molecule is largely present. On the other hand, the very small amount of lime proves that the plagioclase must be a very acid one. Hence it is quite possible that the untwinned feldspar is a soda orthoclase. It has been recently shown[1] that in high alkali rocks, with relatively low lime, a soda orthoclase may be present which optically is scarcely distinguishable from orthoclase. Unfortunately, in the case of these quartz-porphyries the feldspar phenocrysts are almost invariably somewhat kaolinized, and accurate optical determinations are thus prevented.

The groundmass is a mixture of quartz and feldspar, the latter untwinned or twinned according to the Carlsbad law. Striated feldspars have not been seen in the groundmass mixture of these rocks.

[1] L. V. Pirsson: Am. Jour. Sci., Vol. XLVII, 1894, p. 342.

The feldspars are generally present in the short, rectangular form, while quartz forms the cement between them. This type of structure, which may be called the microgranitic, is generally present, but at times passes into a variety where quartz and feldspar are mingled in allotriomorphic grains confusedly interlocked. The monotony of these uniform groundmasses is interrupted only by the phenocrysts and by an occasional grain of iron ore or a crystal of apatite or zircon, the latter sharply bounded by crystal planes. An analysis of an average specimen from one of the intruded sheets from the divide between the headwaters of Fourmile and Checkerboard creeks (Sp. No. 94) gave the following result:

Analysis of quartz-porphyry.

[By L. V. Pirsson.]

	Per cent.
SiO_2	72.38
TiO_2	.10
Al_2O_3	14.71
Fe_2O_3	1.09
FeO	.82
MnO	Trace.
MgO	.70
CaO	.67
Na_2O	4.28
K_2O	4.15
Li_2O	Trace.
H_2O	.92
Total	99.82
Sp. gr	2.61

The composition of this rock is strikingly like that of the granite mass, and the similar relations of the alkalies to one another is very noticeable. It differs in being somewhat lower in lime and iron. Its composition allies it with some of the quartz-keratophyres.

In respect to their state of preservation, these rocks are nowhere found absolutely fresh. The feldspars never have the sanidine habit, while the biotite is nearly always altered to a mixture of chlorite and iron ore, more rarely to muscovite. The groundmass, and often the feldspar phenocrysts, are dotted with leaves of sericite. On fresh fractures also the weathering of the surface is seen extending into the rock as a brown mantle, often to some depth.

QUARTZ-TOURMALINE-PORPHYRY.

An occurrence of a quartz-porphyry with tourmaline, sufficiently common to rank as an accessory component, deserves especial mention.

The rock occurs as an intruded sheet, whose outcrops and talus are found on the lower slopes of the mountain side forming the right-hand wall of the deep and narrow valley of the main upper head of Fourmile Creek, and about 1½ miles south of the present road from White Sulphur Spring to Castle. The mountain side is covered by such a heavy mass of talus that the exact position and thickness of the many intruded sheets at this point can not be accurately determined; their outcrops project above the talus in confused masses. Among them are the exposures of the tourmaline-bearing quartz-porphyry. It is at once noticeable from its very pale, almost pure-white color, tinged pinkish on weathered surfaces. It is so jointed that it breaks out and falls in large blocks along the talus. Under the hammer it is extremely tough and breaks with a splintery fracture. Megascopically the rock consists of a dense, very pale-gray felsitic groundmass, in which lie numerous quartz phenocrysts, from 1 to 2 millimeters in diameter. It is further flecked by small, whitish spots of feldspar, which do not reflect light from cleavage surfaces, and by many dots and dashes of black, averaging from one to several millimeters in diameter. Examined closely, these latter are seen to consist of radial and stellate groups of a black, fibrous mineral with a silky luster. Much more rarely occasional minute masses of bright-purple fluorite are seen, sometimes associated with the tourmaline. There also occur occasionally very small patches of a pale oil-green substance of a waxy luster. Under the microscope the rock is found to possess a normal, fine-grained groundmass, composed of an allotriomorphic mixture of shapeless, interlocking quartz and feldspar grains. In plain light this has a mottled appearance, due to the fact that the feldspar is somewhat kaolinized and cloudy, and thus contrasts with the limpid quartz. In this groundmass are numerous quartz phenocrysts of the usual quartz-porphyry type. The feldspar phenocrysts are also numerous, and consist of orthoclase and plagioclase, the latter a very acid one, since it invariably extinguishes at very slight angles to the twinning lamellæ. In plain light the orthoclase appears clear and colorless, while the plagioclase is always brownish from incipient kaolinization. The plagioclase is sharply idiomorphic and often in groups of several attached crystals. The orthoclase is less idiomorphic, and appears to have been growing in the second period of consolidation; it often incloses small idiomorphic plagioclases.

The occurrence of the tourmaline and fluorite is of greater interest. The former is composed of radial bunches of slender acicular crystals, strongly pleochroic, the ordinary ray a deep sea-green, often a deep indigo-blue or bluish-green, the extraordinary ray a pale reddish-brown. It evidently replaces feldspar, and often the shape of the cavity occupied by the stellate groups is that of this mineral; in other places the needles packed together appear as broad tongues penetrating the feldspar substance; at other times it is seen as shreds and patches diffused through the feldspar. The mineral is easily identified by its pronounced optical characters, and these were confirmed by tests before the blowpipe, which showed the presence of boron. The fluorite appears in the section in precisely the same mode of occurrence, replacing feldspar. It is identified by its isotropic character, its cleavage, and its low single refraction. Small leaves of white mica are also scattered through the feldspars. A few crystals of apatite and zircon were observed, but no ferromagnesian mineral has been seen either under the microscope or in the hand specimen. The iron and magnesia present appear to be all in the tourmaline. An analysis of the rock resulted as follows:

Analysis of quartz-tourmaline-porphyry from Fourmile Creek.

[By L. V. Pirsson.]

	Per cent.
SiO_2	74.82
TiO_2	.25
Al_2O_3	13.80
Fe_2O_3	.37
FeO	.30
MnO	Trace.
MgO	10
CaO	.17
K_2O	4.81
Na_2O	4.33
Li_2O	Trace.
H_2O (ign)	.83
Total	99.78
Sp. gr	2.59

The similarity between this analysis and that of the normal variety of quartz-porphyry is striking, the difference being in a smaller amount of lime, iron, and magnesia, and slightly higher silica. The alkalies are about the same and almost exactly like those in the granite; the same ratio of potash to soda obtains, and it is evident that here also the albite molecule plays a conspicuous part in the formation of the feldspars.

The chief interest in the rock lies, of course, in the presence of the tourmaline and fluorite. The former mineral seems to be of rare occurrence in quartz-porphyry and rhyolite, though common in granites. Phillips[1] mentions it as occurring in a number of quartz porphyry dikes (elvans) in Cornwall, where it occurs, as in the present case, in detached crystals or shreds, in radial groups, and also as filling spaces left by decomposed feldspars. Rosenbusch[2] gives an occurrence on the Auersberg in the Hartz Mountains, while Zirkel[3] adds Wagenberg in the Odenwald, at Elba, near Lugano, and on Monte Mesma on the lake of Orta, and D'Achiardi[4] in quartz-porphyry dikes in Donoratico, in blue

[1] Quart. Jour. Geol. Soc., 1875, p. 335.
[2] Mikro. Phys. Gesteine, 1887, p. 365.
[3] Lehrb. Petrographie, Vol. II, 1894, p. 154.
[4] Atti della Soc. Tosc. di Sci. Nat. Pisa, Vol. VII, 1885, p. 21.

and bluish-green crystals, their identity confirmed by tests for boron. Of its occurrence in true effusive rhyolites we have found only one mention, that by Iddings[1] in the spherulites from Obsidian Cliff.

Fluorite seems to be of still rarer occurrence. Rosenbusch[2] mentions two localities: Halle on the Saale, and Altenhavn in Saxony. It does not appear to have been observed in rhyolite.

The origin of these two minerals is to be referred to the pneumatolitic action of fluorine and boron vapors included in the igneous magma and given off in the process of cooling and crystallization. These vapors have evidently attacked the compounds first formed, resulting in the production of these minerals. It is of interest to note here that the contact breccia filled with seams and veins of tourmaline is at no great distance, and this is a fact which also bears witness to the active agency of mineralizers in the cooling magma.

MUSSELSHELL QUARTZ-PORPHYRY.

Occurrences of large masses of intrusive porphyry on the North Fork of the Musselshell, near the mouths of Checkerboard and Flagstaff creeks, present collectively a certain habit of the rock which is somewhat different from that of the quartz-porphyries of Castle Mountain. The groundmass is more granular, less dense and felsitic in appearance; quartz phenocrysts are rarely seen, and they are generally quite thickly dotted with small, glittering idiomorphic tablets of biotite. The rocks range from white to a pale pink in color, the latter being very common. They are abundantly filled with pale yellowish-white feldspar phenocrysts from 2 to 4 millemeters in length. There are also small rectangular spaces filled with yellowish-brown limonite, the pseudomorphs of some former phenocryst.

A very dense white variety occurs as a facies of the most northern mass on the banks of the little creek cutting through it on the east side of the Musselshell. With this exception the rocks are nearly everywhere of the type described. Under the microscope the groundmass is seen to vary somewhat in granularity in the different occurrences; in structure it ranges from allotriomorphic to micrograniteid, the small feldspars in the latter rather idiomorphic and short-rectangular in section, the quartz filling the interspaces. The phenocrysts are quartz, which is quite rare, a plagioclase near oligoclase or albite-orthoclase, biotite similar in character to that found in the rocks on Castle Mountain, a little apatite, iron ore, and zircon. The dense white variety is almost devoid of phenocrysts.

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[1] Bull. Philos. Soc. Washington, Vol. XI, 1891, p. 455.

[2] Mikro. Phys. Gesteine, 1887, p. 365.

An analysis of a typical specimen (No. 197), whose groundmass shows a tendency toward the micropoikilitic structure, gave—

Analysis of quartz-porphyry from the Musselshell River.

[By L. V. Pirsson.]

	Per cent.
SiO_2	71.67
TiO_2	.10
Al_2O_3	15.82
Fe_2O_3	1.18
FeO	.35
MnO	Trace.
MgO	.13
CaO	.25
Na_2O	4.46
K_2O	4.45
Li_2O	Trace.
H_2O	1.21
Total	99.62
Sp. gr	2.60

This analysis shows a very striking resemblance to the analyses already given of the acidic rocks of Castle Mountain, especially in the relation of soda to potash. Although no direct geologic relationship can be traced in the field between the two occurrences, this close agreement in chemical and mineral composition seems to clearly indicate that they have had a common origin and that the magma which formed this porphyry ascended through a different conduit from the same reservoir which formed the Castle Mountain mass.

Near the juncture of Warm Spring Creek with Woodman Creek, or in other words at the head of the South Fork of the Musselshell, occurs a small butte formed by an intrusion of quartz-porphyry into Cretaceous strata. Megascopically and microscopically the rock is in every way similar to the quartz-porphyries of Castle Mountain. The grain is fine and has a tendency to micropoikilitic structure, but is in general allotriomorphic. The phenocrysts are quartz, plagioclase, and orthoclase of the usual type. The presence of some former ferromagnesian mineral—biotite or hornblende, or possibly both—is indicated by collections of limonite grains mixed with serpentine and at times calcite. These give the rock a general brownish tone. This is the most southerly occurrence of a rock of undoubted Castle Mountain type, and is therefore of interest.

FELSITE-PORPHYRY.

This name is used in the sense of Tschermak,[1] and without reference to geologic age (of which indeed Tschermak himself makes no mention), to designate those rocks with dense groundmasses of quartz

[1] Sitzungsber. K. Akad. Wiss., Wien, LVI., 1867, note 11, p. 305.

and alkali feldspar in which lie orthoclase phenocrysts, but none of quartz, and which have the chemical composition of a quartz-porphyry. Although large portions of the Musselshell porphyry might properly come under this designation, at Castle Mountain itself the rock has only a few limited occurrences and is of such a nature that it forms really a transition stage into the quartz-free porphyries, to be described later.

The great dike which rises like a wall above the talus-covered slopes of the right canyon wall of upper Fourmile Creek, and which has been mentioned on page 65, is an example of this type. The rock has been somewhat altered, and the former ferromagnesian components, which are thought to have been biotite and hornblende, are replaced by masses of hydrated iron oxide, calcite, and other decomposition products. The rock has a rusty tint from the iron oxide. The phenocrysts are orthoclase and plagioclase, both greatly altered, which lie in a groundmass of quartz and feldspar, the latter predominating. The relation of the rock to quartz-porphyry is shown by the fact that although quartz as a phenocryst is generally wanting, in a few places in the rock mass it is abundantly developed, and it is then precisely similar to that already described under the normal type of quartz-porphyry. A section cut from the contact with the Belt shales, which have been highly indurated into a greenish hornstone, shows in the porphyry a pronounced parallel arrangement of the numerous phenocrysts into a flow structure parallel with the sides of the dike. This is especially shown by the feldspars, which have a lath-like development. It proves that they had already crystallized out when the viscous mass was intruded. The groundmass in this portion of the dike has all the appearance of a devitrified glass, and is peppered through and through with dusty globulitic material.

The large dike which is found cutting the Cambrian limestones on the right side of the Fourmile Creek near its sharp turn to the northwest above Reed's ranch is somewhat similar to the above, but has less quartz in the groundmass and is a transition form into syenite porphyry; it might, indeed, be called a rather acid type of that rock. Megascopically it is seen to consist of abundant large pinkish or yellowish orthoclase crystals, often half an inch long, and with a deep stain around their edges, with small white striated feldspars and small black hornblendes lying as phenocrysts in a dense gray groundmass. Under the microscope the rock is seen to be highly altered. It contains large amounts of calcite, some of which may indeed be material derived from the calcareous rocks into which it has been injected, while some is plainly secondary. The hornblendes are often entirely decomposed and their places filled with calcite, which is not a confused crystalline mass, as is so often the case, but a single individual crystal with uniform polarization, but with all the idiomorphic form and characteristic angles of the original hornblende. Such a crystal often includes masses of chlorite material, from the alteration of the original hornblende, which has not been removed from the cavity and around which the calcite has grown. Its orientation does not seem to bear any relation to the original hornblende. The explanation of this rather curious pseudomorphism is undoubtedly to be sought in the fact that the percolating water which has been the active agent in the decomposition of the rock must have been highly charged with the bicarbonate of lime in solution, derived from the limestone strata through or over which it had to pass to reach the dike below, and this accounts, at least in part, for the large amount of carbonates in so acid a rock. Where the hornblende still remains it is of the common green variety and incloses much brown biotite, the latter also occurring idiomorphically by itself. The groundmass consists of allotriomorphic singly twinned feldspar, interspersed with considerable quartz, which is also generally shapeless, but in several cases was noted to possess clearly cut hexagonal outlines.

The dike which outcrops on the hill to the northeast of the above, and of which, indeed, it may be the continuation, though direct proof is wanting, is megascopically almost precisely similar. Under the microscope it differs chiefly in the fact that the ferromagnesian components do not appear to have formed as phenocrysts, but are scattered in small shreds and rods through the groundmass, the biotite predominating over hornblende. This produces, so far as the groundmass is concerned, a resemblance to some minettes, but the rock is far too rich in silica, alkalies, and alumina, being essentially a feldspar rock, to be classified under that type. Considerable interstitial quartz is present, but less than in the former rock. It is also considerably altered. In reality it is a syenite-porphyry, but from its resemblance and possible geological connection with the dike previously described, is mentioned under this heading.

Another type intermediate between felsite-porphyry and a true syenite-porphyry is furnished by a series of rocks that occur, as shown on the map, below the town of Castle, intruded into Cretaceous strata in a series of dikes and sheets. Though they differ somewhat among themselves in megascopic appearance, as regards color, size of phenocrysts, and state of preservation, yet the microscope shows that they all belong to one type, and the best and freshest occurrence is here selected for description. Megascopically the rock consists of a dense gray groundmass which is thickly dotted with very small black hornblende and mica phenocrysts and much larger ones of a white feldspar, which is not sharply idiomorphic but rather rounded in outline, and which averages about 2 millimeters in diameter. Under the microscope the groundmass resolves itself into a very fine mass of unstriated feldspar, mixed with a little quartz, generally allotriomorphic, but at times showing a tendency to a trachytoid structure. The quartz is sometimes rather idiomorphic, and occasionally, though very rarely, rises to the position of a very small phenocryst. It plays in toto but an unimportant rôle as one of the rock-forming constituents. The feldspar phenocrysts are chiefly orthoclase with a smaller amount of an acid plagioclase. The hornblende is present in small, well-formed crystals bounded by the common forms *m* (110), *b* (010), *r* (011), and *c* (001). It is always the ordinary green variety, with a small extinction angle. Also in a few instances brown basaltic allanite, with high extinction angle, has been noticed. The biotite is of a yellow-brown color and possesses, for the mineral, an extraordinarily small absorption; it is probably somewhat bleached, and is, moreover, nearly always, even in the freshest examples, partially altered to chlorite. Both the hornblende and mica occur in extremely small crystals, at times nearly reaching the dimensions of the groundmass. Occasional crystals of apatite, zircon, and iron ore complete the list of minerals. An analysis gave the following result:

Analysis of porphyry from Castle.

[By L. V. Pirrson.]

	Per cent.
SiO_2	65.87
TiO_2	.37
Al_2O_3	16.82
Fe_2O_3	1.58
FeO	1.23
MnO	Trace.
MgO	1.54
CaO	2.65
Na_2O	4.72
K_2O	3.15
H_2O	1.43
Total	99.36
Sp. gr	2.62

This analysis agrees with the mineral composition, but indicates that the albite molecule must be more largely present among the feldspars than is indicated by the study of the sections.

The other occurrences at this locality are quite similar to the above; at times the groundmass is somewhat coarser and a greater tendency to a trachytoid structure becomes evident, but the mineral combination remains the same. These other rocks are generally more altered, containing quantities of calcite, chlorite, limonite, and kaolin.

QUARTZ-FREE PORPHYRY (SYENITE-PORPHYRY).

Feldspathic porphyritic rocks free from quartz, in which orthoclase rules, are found in a number of occurrences in the Castle Mountain district. For purposes of description they may be divided, according to their origin, into three groups: those of the Castle Mountain mass belonging to the Castle Mountain center of eruptive activity proper; those of the intruded masses and sheets of Black Butte, shown on the map in the extreme southwest corner; and the numerous intrusive sheets in the Cretaceous strata, which form the broad, open valley of the south branch of the Musselshell, and which, from their mineral combination and peculiar habit, are known to be of Crazy Mountain type and origin.

The quartz-free porphyry of Castle Mountain is confined to a limited number of dikes. The most important occurrence is in a series of three parallel dikes crossing the limestone hill northeast of Blackhawk, as mentioned in the previous chapter. These dikes are all composed of the same type of rock; megascopically it is dense but perceptibly granular and of a dark-gray color, spotted with white, waxy-looking feldspars of rounded, ill-defined form. A little mica is seen, but the ferromagnesian component is generally chloritized, forming dull-greenish spots.

Microscopically the rock is seen to be very simple, consisting of phenocrysts of orthoclase and some plagioclase in a groundmass chiefly of unstriated feldspar having a trachytoid structure. No primary quartz is seen. Hornblende was probably originally present, but is now a mass of calcite, chlorite, limonite, serpentine, etc. The micas have also nearly disappeared, and in general the rock is much altered and kaolinized, though the feldspars in the most southerly of the three dikes are still fresh enough for distinct determination. On account of their altered condition no analysis of these rocks has been made. If they were named according to the present German classification, but without reference to their geologic age or mode of occurrence, they would undoubtedly be classed as orthophyres. From the position of these dikes it seems quite possible that they may be offshoots from the diorite mass, though their composition allies them with the granite.

Another rock which comes in this class is the dike a few rods below Reed's ranch on Fourmile Creek. This dike is cut through by the stream and the rock is intruded in the green shales that form the upper part of the Carboniferous series, as shown on the map. It is a brownish rock, with very fine-grained groundmass holding white feldspar and black biotite phenocrysts. Under the microscope its composition is seen to be very simple. It is composed of biotite, feldspar, iron ore, and a little quartz. The biotite has the deep-brown color and strong pleochroism found in the Castle Mountain rocks. In the feldspar phenocrysts orthoclase rules, but some plagioclase is present. The groundmass is composed of small microlitic feldspars which are unstriated, packed in a trachytic-like felt, dusted through with ferritic material. The quartz is scattered in small areas and grains and appears to be largely secondary. The rock is considerably altered, and if any glass was originally present it has been devitrified. The rock might well be classed as a trachyte.

Similar to the above, but greatly altered, is the dike which is intruded in the Cambrian strata just north of the great bend in Fourmile Creek and near the large dike previously described. So also is the dike cutting the breccias on Fivemile Creek. In both the mica has nearly disappeared and great quantities of calcite are present.

BLACK BUTTE PORPHYRY.

The several sheets and intrusions at Black Butte are all closely related rocks, augite and porphyries inclining strongly to porphyrites. The rock which composes the highest point of Black Butte itself is of a pale-brownish color, dense in texture, and thickly crowded with feldspar phenocrysts, which, as they are somewhat rounded in outline and tinged in most cases like the rock itself, are not strongly prominent. Ferromagnesian components are rare.

The microscope reveals that the groundmass is made up of ragged patches of unstriated feldspar with a little quartz in very fine grain. The feldspar phenocrysts are extremely numerous and vary greatly in size, from 5 millimeters in diameter to transition forms into the groundmass. The unstriated feldspar is predominant and is zonally built; the striated one is a rather acid plagioclase, to infer from the great number of uniformly small extinction angles to the twinning lines; it shows both albite and pericline twinning. The ferromagnesian component is a green diopside, like augite, very fresh and clear, but in small phenocrysts and never abundant. Titanite is common in characteristic outlines. The rock is an augite-porphyry.

Numerous inclusions were observed, of what appears in the hand specimen to be hornblende-schist in angular fragments up to an inch or so long. Sections of these show that they are composed chiefly of a green pleochroic hornblende, with a large amount of orthoclase and much less plagioclase, and without quartz. The structure is schistose and allotriomorphic, the feldspars in rounded grains embedded in and against the hornblende so that no crystal boundaries are seen in either mineral. Occasional portions of the mass are of finer grain, and in them occurs much black iron ore, a constituent which is nearly lacking in other parts of the rock. Such areas recall the transformation and recrystallization of some large crystal of an inclusion, examples of a process which has been so beautifully figured and described by Lacroix[1] in his recent admirable memoirs on the inclusions of volcanic rocks. It would seem as if these inclusions were of some deeply seated rock torn off by the ascending magma and recrystallized, the minerals being extremely fresh and well preserved.

Below this mass, which forms the summit, several intrusive sheets outcrop on the north and east sides of the butte, the rocks being in general so greatly altered that the study of thin sections reveals nothing beyond what has been stated for the upper mass. On the east

[1] Les enclaves des roches volcaniques: Ann. Acad. Macon, Vol. X, 1893.

side, at an altitude of 5,400 feet and just above the lake-bed deposits, there occurs in the Belt shales an intrusive mass or sheet where the rock, there well preserved, shows a somewhat different character. In the hand specimen it resembles in its habit some of the porphyrites which occur in the Absaroka Range. It is of a dark-gray color, thickly spotted with feldspar phenocrysts which rise to one centimeter in diameter. These lie in a groundmass that to the naked eye appears finely granular and composed of feldspar and hornblende. Under the microscope, however, the groundmass is found to consist of these small hornblendes and feldspars lying in a microcrystalline, evenly granular mixture of orthoclase with some quartz. If we were to judge by the relative sizes of the crystal components, the rock would therefore represent three stages of crystallization; as a matter of fact, between the large and small feldspar phenocrysts, every gradation in size may be found, but it is evident that what is generally called the "intratelluric stage" had progressed very far before the rock was intruded. The feldspar is chiefly an unstriated one, zonally built and often showing some kaolinization. Plagioclase is present, but is not common. The hornblende is the same green variety that has already been described as occurring in the Castle Mountain porphyries. It is generally idiomorphic, often in very slender prisms, sometimes in shreds and patches. There is considerable titanite present in good crystals. It is remarkable how constant the association of this mineral is with hornblende-orthoclase rocks. Considerable iron ore is present, and some apatite; also a little white mica as an alteration product.

From what has been said it is therefore evident that the igneous rocks of Black Butte are closely related to those of Castle Mountain. They display, to use the apt term of Iddings,[1] a large amount of "consanguinity" with them, and the only observed variation in mineral character is in the zonal structure of the unstriated feldspar, a phenomenon rarely observed in the Castle Mountain rocks.

CRAZY MOUNTAIN ROCKS.

Under the heading of quartz-free, intrusive porphyritic rocks may be here briefly mentioned the occurrence of the great number of sheets which fill the Cretaceous strata in the southeast portion of the district. They are composed chiefly of acmite trachytes with very large feldspar phenocrysts, and of those holocrystalline rocks of tephritic character to which Rosenbusch[2] has given the name of theralite. Both of these types have been preliminarily described by J. E. Wolff,[3] to whom their discovery is due. A detailed description of them will be published in a memoir by Professor Wolff and W. H. Weed on the Crazy Mountains.

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[1] Origin of igneous rocks: Bull. Philos. Soc. Washington, Vol. XII, 1892, p. 128.

[2] Phys. Mass. Ges., 1887, p. 248.

[3] Notes on Petrog. Crazy Mts., etc.: Northern Transcontinental Survey, 1885. Cf. also Geol. Crazy Mts.: Bull. Geol. Soc. America, Vol. III, pp. 445-452. Acmite-trachyte: Bull. Mus. Comp. Zool. Harvard Coll. (Geol. Ser., Vol. II), Vol. XVI, No. 12, 1893.

It will be unnecessary, therefore, to do more than refer to them here. A few porphyrites have been found in the southern part of the Castle Mountain area, which Professor Wolff, who has kindly examined the sections, pronounces to be of distinct Crazy Mountain type.

In addition to these there occur also several intrusive sheets whose direct source is doubtful, partly because of their decomposed state and partly because of their mineral nature. A certain type of these rocks is an augite-porphyrite, which exhibits some peculiar features. The rock is a dark stone-gray or blue, thickly dotted with small white feldspar phenocrysts, which are very slender and appear like white scratches on the surface. In thin section these feldspars are seen to be plagioclase, and with such a high extinction angle at times that they must belong to the labradorite group. Both albite and (more rarely) pericline twinning are seen. The feldspars contain large cavities filled with a dusty brown devitrified glass. The base also consists of this dusty brown devitrified glass filled with globulitic material, often arranged in plumose patterns. In this lie slender, lath-like microlites of an acid plagioclase, also twinned in striæ, scattered about like straws, and which in plain light are seen as colorless cuts and slashes in the brown base. Originally some augite was present, but it is completely changed to serpentine and calcite. Biotite is rare, being generally altered to a mass of chloritic, ferruginous material.

This type occurs in several intrusive sheets, one of which is in the Cretaceous strata immediately below the small mass of Carboniferous and the diorite on Bonanza Creek, and it is also found, with slight modifications, in a curious, winding serpentine dike cutting Cretaceous strata and intruded theralite sheets in the lower basin of Bonanza Creek. A rock of the same general character, but nearly holocrystalline, occurs in the synclinal Cretaceous basin north and east of the great bend in Bonanza Creek, but it is much weathered. It is believed to be a porphyrite of Crazy Mountain origin.

LAMPROPHYRE ROCKS.

INTRODUCTORY.

It is not the intention of the authors to present here a discusion as to whether or not certain classes of rocks should be termed distinctively "dike rocks," as has been done by Rosenbusch. Whether a given magma will take the form of dikes, sheets, or intruded masses depends upon the physical conditions relating to the rock masses into which it is forced. And if the same physical conditions as regards pressure and cooling are present, as they well may be, then we may find the same rock as a sheet, a dike, or a small intrusive mass indifferently.

Iddings[1] has pointed out that the effusive equivalents of the rocks

[1] Origin of igneous rocks: Bull. Philos. Soc. Washington, Vol. XII, 1892.

which have been termed "dike rocks" occur, but they were crystallized under different physical conditions and therefore are structurally, and generally mineralogically, different from the deep-seated forms. In a most admirable paper on the basic eruptive rocks of Gran, in Norway, Brögger[1] shows that not only do camptonites and bostonites occur in sheet as well as in dike form, but he also regards these rocks as differentiation products of an olivine gabbro, and claims, therefore, that their occurrence is not necessarily indicative of the presence of a definite type of granular plutonic rock, as had been formerly supposed. Nevertheless, since it is true that in regions where erosion has been sufficient to expose the central stocks or cores of former eruptive activity, there nearly always occur certain highly differentiated forms of the general magma in sheets or dikes, it would be well to have general terms by which to express the contradistinction of the basic and the acid types. One is distinguished by the high ferromagnesian content, the other by the alumina, alkali, and silica. It is here proposed to call the basic types simply lamprophyres, or lamprophyric rocks, without reference to their mode of geologic occurrence.[2] In or around the Castle Mountain center these rocks are rare. They are limited to a few dikes, one or two intrusive sheets, and one small intrusive mass. So far as they correspond with well-known and already-described types they will be named accordingly.

AUGITE-VOGESITE.

The basic dike which cuts the Belt shales and intruded quartz-porphyry on Fourmile Creek near the contact with the central granitic stock has already been mentioned and a view of it given in Pl. IX. Megascopically the rock is a very dark stone-gray with a greenish tone. On a fractured surface an occasional white spot is seen which reflects light from the cleavage surface of a small calcite inclusion. The grain in general is rather dense, so that the individual components can scarcely be recognized by the eye. The rock, following a cross section of the dike, has in fact three grades of crystallization, which pass insensibly into each other. In the central portion, which forms the greater part of the cross section, it is very fine granular, but feldspar cleavages can be recognized; this passes into a narrower zone on each side where they can with difficulty, or not at all, be discriminated, and finally at the contact there is a very narrow selvage band which is nearly black and is very dense. Microscopically the rock is seen to be composed of augite, hornblende, iron ore, a little plagioclase, orthoclase, calcite, and some decomposition products. The augite is a colorless diopside in phenocrysts which rise to 1 millimeter in length. They are all more or less altered with formation of serpentine and other decomposition products. They are quite numerous and are often gathered in

[1] Quart. Jour. Geol. Soc. London, Vol. L, February, 1894, p. 15.

[2] Cf. Complementary rocks and radial dikes: Am. Jour. Sci., Vol. L, August, 1895.

groups. They lie in what is, compared to them in size, a groundmass, composed of orthoclase pegged through and through with slender crystals of a brown hornblende and dotted with the iron ore in small grains. The ore is usually found around the edges of the augite crystals, clothing their outlines in the section like a string of beads. It does not, however, appear to be secondary. The feldspar is clear and colorless, filled with great quantities of very long, slender, apatite prisms; it is allotriomorphic, and in rather broad, irregular masses showing Carlsbad twinning. The slender hornblende prisms are a pure brown in color, slightly pleochroic, and with a small extinction angle. Calcite, while undoubtedly present, largely as a decomposition product, is also seen at times to occur in such a manner as to suggest a primary origin. It is then present in the angular interspaces between the feldspars and not connected with any lime-bearing mineral. Here frequently the fresh hornblendes pin it and the feldspars together. No decomposition products are present, the minerals are fresh, and it is difficult to believe that the calcite has been secondarily introduced. Similar facts have been observed by other investigators, and Zirkel gives an excellent résumé of the occurrence of calcite in this class of rocks under the heading of kersantite.[1]

An analysis of the rock (Sp. No. 103) yielded the following result:

Analysis of augite-vogesite, Fourmile Creek.

[By L. V. Pirsson.]

	Per cent.
SiO_2	45.15
TiO_2	2.80
Al_2O_3	15.39
Fe_2O_3	2.76
FeO	5.64
MnO	.14
MgO	6.38
CaO	8.83
Na_2O	2.67
K_2O	2.77
Li_2O	Trace.
H_2O	2.85
P_2O_5	.56
CO_2	4.27
Total	100.21
Sp. gr	2.70

The carbonic acid shows the considerable amount of carbonates present. The large quantity of titanic oxide is also noticeable, and the iron ore is evidently ilmenite. It is also interesting to note that the ratio of potash to soda remains the same as in the acid rocks which the dike accompanies.

[1] Lehrb. Petrog., Vol. II, 1894, p. 516.

The second phase of crystallization is quite similar, save that the grain is finer and the augite phenocrysts are less numerous.

The narrow selvage band at the contact shows more of interest, however. Immediately at the contact it is dense and black and does not transmit light, being opaque even in thin section. It is, without doubt, a basic glass charged with ferritic globulites. It is crowded with augite phenocrysts, almost entirely altered to masses of serpentine and calcite. From this stage, as one passes inward, the degree of crystallization becomes rapidly greater, light passes through the section, and the rock is here a mass of minute microlites which are so small and densely packed that only the ore grains can be told with certainty. Then occasional lath-like feldspars appear among the microlites; they become larger and more numerous, the grains of the other constituents increase in size and their distances from each other become greater, and the rock assumes a structure and appearance not unlike many dense basalts, save for the greater abundance of the ferromagnesian elements. Up to this point nothing which can safely be referred to hornblende appears in the rock; the grains seem to be entirely augite and iron ore. The variations in crystallization which have been described occupy not more than half an inch in distance. The rock then passes more gradually into the types previously described. The quartz-porphyry does not appear to have been changed by the intrusion of the dike; its structure is micropoikilitic.

The existence of this dense saalband is of value in demonstrating that the magma forming the dike was injected into rocks that had already become comparatively cold, and when we consider that it is upon the immediate edge of the great central stock which must have been radiating heat in enormous quantities through a long period of time, it is evident that the intrusion of this lamprophyre dike was long subsequent to the acid intrusions it cuts.

A basic intrusive sheet which appears on the spur above, between the headwaters of Fourmile and Checkerboard creeks, has in many ways a close analogy to this dike, and resembles that stage where it is mentioned as appearing like a basalt. It is, however, so greatly altered, with the dark lime, iron, and magnesia components changed to epidote, serpentine, and other products, that no safe conclusions can be drawn regarding it.

MINETTE.

The small mass which has been intruded into the Cambrian strata where Fourmile Creek empties into the North Fork of Smith River is composed of a rock which, in the present generally accepted system of classification, should be termed a minette, in that it is composed essentially of biotite and orthoclase with phenocrysts of biotite and none of feldspar. It contains accessory hornblende, and thus shows a tendency to vogesite.

To the eye the rock is dense, of a somewhat greasy appearance, and a rather dark gray in color. Through this groundmass are scattered numerous black mica phenocrysts of rather small size. The microscope shows the rock to be panidiomorphic in structure, and composed of orthoclase, biotite, iron ore, and apatite, with phenocrysts of hornblende and biotite. The biotite is, as usual, strongly pleochroic, and, like all the biotites of Castle Mountain, is practically uniaxial, at least no opening of the cross can be observed. The hornblende is peculiar. It is present in rather slender pale-green prisms, and is also zonally built, the outer shell being of a much paler tint than the interior. Its angle of extinction is small, its double refraction weak. It is, indeed, the same hornblende as that found in the typical vogesites from the Odenwald and Vosges, which have become classic through the researches of that great master of petrography, Rosenbusch. In the order of crystallization the biotite commenced, since it is inclosed at times in the hornblende. As the rock as a whole is extremely similar to well-known types of minette, it needs no further comment on its mineral association. It grows richer in feldspar toward the center, and shows a tendency toward the quartz-free porphyry or trachytes heretofore mentioned. The feldspar does not, however, occur in distinct phenocrysts.

At the contact the rock is a greenish-brown glass filled with hornblende, and more rarely mica phenocrysts. The glass is dusted through with globulitic material. A large broken hornblende in the section shows clearly that this mineral was present in the viscous mass when it was forced into its present place.

The limestone at the contact has been changed into saccharoidal marble.

MONCHIQUITE.

This name has been given by Rosenbusch[1] to a variety of lamprophyric rocks which consist of olivine, pyroxene, and biotite or hornblende in a colorless glass base. In this country they have been chiefly investigated by Kemp,[2] in whose excellent papers will be found a summary of their history and a complete bibliography.

The dike which occurs in the Belt shales on the left bank of Willow Creek is composed of a rock which is most nearly related to the monchiquites. The outcrop of the dike has been prospected for ore, and some quite fresh material has been thrown out of the trench. The rock is black and basaltic in appearance and contains abundant grains of clear yellow olivine as phenocrysts. In thin section it appears at first glance to be composed almost wholly of augite, so abundant and so thickly crowded are the crystals. Olivine, biotite, iron ore, and apatite are, however, also present in essential quantities, and are lying in a colorless base dusted through with brownish globulitic material. The augite is zonally built; the larger individuals are often greenish in the center and surrounded by a purplish-brown mantle, which has a lesser angle

[1] Min. und Petr. Mitt., XI, 1890, p. 445.

[2] Arkansas Geol. Surv., II Ann. Rept., 1890, Vol. II., Ign. Rocks, p. 394; Bull. U. S. Geol. Survey No. 107, Trap Dikes, etc., 1893, p. 32; also other papers mentioned above.

of extinction and a great dispersion of the optic axes. The smallest augites are similar to this mantle. One might by analogy infer that these and the outer shell of the large ones contained titanic acid.

The olivine is in general quite fresh, sometimes more or less altered to serpentine. In a few cases the augites have also been altered to chlorite and calcite. The biotite is of the usual red-brown variety. An inclined extinction was not observed in it. The base in which these minerals lie is small in amount and filled with microlites of the larger crystals. In places it is wholly isotropic; in other spots it shows a feeble aggregate polarization. No outlines that could be referred to nephelite appear in such spots, and it is probably due to zeolitic alteration. Nothing that would suggest leucite, either in outline or arrangement of inclusions, could be found. It looks like a glass partially altered.

An analysis of the rock gave the following result:

Analysis of monchiquite from Willow Creek.

[By L. V. Pirsson.]

	Per cent.
SiO_2	42.46
TiO_2	2.47
Al_2O_3	12.04
Fe_2O_3	2.19
FeO	5.34
MnO	.16
MgO	12.40
CaO	12.14
Na_2O	1.21
K_2O	2.68
Li_2O	Trace.
CO_2	.55
P_2O_5	.84
H_2O	4.03
Total	99.51
Sp. gr.	2.94

From the large amount of titanic acid it is evident that the iron ore must be ilmenite. The water must be derived, in part at least, from the partially zeolitic base, for although in some cases the olivines are changed to serpentine and the augites are chloritized, on the whole there are certainly not enough decomposition products present to account for so much water. As a matter of fact, the rock is very fresh for one of this class.

The relation of the magnesia to the lime is exactly what should be expected from the great preponderance of augite.

A consideration of the analysis, especially if the ratios of the oxides be taken as shown on page 136, indicates that if the residual base had crystallized it would probably have formed some feldspar. The amount of alumina is almost double that of the alkalies, and some may therefore be reasonably expected to be present in the augite. The biotite also would demand some. In all these cases, however, the alumina demands an equivalent of alkalies, and it seems quite possible, therefore, that, had the crystallization been complete, melilite would have been formed.

On treatment with acids the rock powder gelatinizes. On account of the olivine and the small amount of the isotropic base, the authors are not able to say positively that the latter is soluble in acids, but from the amount of gelatinization they believe that it is.

A comparison of this rock, and especially of its analysis, with the rocks described by Rosenbusch and Kemp shows that in mineral composition it approaches most nearly the rocks described by the latter. Professor Kemp has kindly examined a section of it, and states that it resembles most remarkably many of those described by him. In chemical composition, however, it approaches most nearly the rock from Rio do Ouro, Serra de Tingua, of which an analysis is given by Rosenbusch. It differs from it in being somewhat higher in magnesia and lower in soda.

On comparing it with the analyses given by Kemp it became apparent that there were serious discrepancies between the petrographical description of the rocks given by him and the accompanying analyses. On communicating with Professor Kemp regarding this point, the authors received in reply the following note, which he desired them to insert at this point:

In Bulletin 107 of the United States Geological Survey—on the Trap Dikes of the Lake Champlain Region—the analysis of the monchiquite dike (No. 14) contains elements of improbability, and it was felt necessary to have the analysis repeated. This has been kindly done with great care by Dr. H. T. Vulté, instructor in chemistry in Columbia College, with the results given below. These differ in important essentials from the results of the earlier analysis, and show the rock to be provided with the normal amount of magnesia, thus conforming to the general type. This latter analysis should therefore replace the earlier one, and the one given of Dike No. 2 (likewise on page 34) by the same chemist is to be considered of very questionable accuracy.

Analysis of monchiquite from Shelburne Point, Vermont.

	Per cent.
SiO_2	45.58
TiO_2	Not det.
Al_2O_3	15.87
Fe_2O_3	4.65
FeO	6.37
MnO	Trace.
CaO	9.91
MgO	8.32
Na_2O	3.42
K_2O	1.61
Loss. Ign. CO_2H_2O, etc	3.14
Total	98.87

As observed by Professor Kemp, this new analysis agrees fairly well in its important details with those given by Rosenbusch. From this point of view it is difficult to understand why Zirkel[1] objects to rocks being placed in this class when they have the same mineral composition and structure, if they do not possess the same exact chemical composition, as the types described by Rosenbusch. A very great variation in composition in important particulars would of course throw any rock out of a given class, but a certain latitude is necessary and must be allowed in any system of classification. Under the minettes, Zirkel[2] presents as typical examples rocks which vary in percentage composition as follows, taken in round numbers:

	Per cent.
SiO_2	45 to 57
Al_2O_3	11 to 16
Fe_2O_3	0 to 8½
FeO	0 to 8½
MgO	5½ to 10½
CaO	5½ to 12
Na_2O	½ to 3
K_2O	3 to 10

If such large variations as these are not sufficient to cause rocks showing them to be placed in separate classes, it does not seem to the writers logical to object to rocks being placed together whose variation is much less and which have the same structure and mineral composition.

The petrological significance of this rock in its present occurrence will be discussed in the following chapter.

DIABASE.

The two occurrences of this rock have been mentioned in the preceding chapter. In the hand specimen it appears quite fresh on fractured surfaces, but in general the sheets have been much jointed and on such surfaces have weathered to a rusty brown. The rock is so coarse grained that the ophitic arrangement of the feldspars may be seen with the naked eye.

Under the microscope the rock appears as a quite fresh typical diabase in all respects. No olivine is present. In the occurrence at the head of Warm Spring Creek, where the rock is rather coarse grained, micropegmatitic intergrowths of quartz and orthoclase are common in the angular interspaces between the feldspars. The rock is thus precisely similar to the occurrence on Smith River (Deep Creek) described by Lindgren.[3] The descriptions, indeed, of the diabases observed by Lindgren in this region apply so well to the occurrence at Castle Mountain that no further comment is necessary. Diabases containing micropegmatitic intergrowths of quartz and feldspar have since been described by G. H. Williams.[4]

[1] Lehrb. der Petrog., Vol. III, zweite Aufl., 1894, p. 6.
[2] Idem, Vol. II, p. 349.
[3] Tenth Census, Vol. XV, p. 736.
[4] Bull. U. S. Geol. Survey No. 62, Greenstone Schists, etc., 1890, p. 141.

CHAPTER VII.

MICROSCOPICAL PETROGRAPHY OF THE EXTRUSIVE ROCKS, OR LAVA FLOWS AND BRECCIAS.

The lava flows are confined to rhyolites and basalts, and the field evidence indicates that the former are the older. The mode of occurrence of the rhyolite, and facts connected with its micro-structure, indicate that it was ejected in an extremely thick, viscous condition, while the basalt, on the contrary, was quite fluid and mobile—facts in accord with the observations of other geologists. The details in regard to the geologic occurrence of these rock masses have been given in a preceding chapter.

RHYOLITE.

In outward appearance this rock shows considerable variation. Not only do the various occurrences differ from one another, but even in the same one there will be found at times a variation from place to place. Thus, in ascending the great hill of rhyolite which lies on the right-hand side of Fourmile Creek, and around which it curves, one finds on the western slope a talus of dark-yellowish to reddish-brown angular fragments. These show most characteristic lines of flow motion—wavy, twisted, and sinuous—brought out best on a weathered surface by a difference in color depending on the iron oxide in the rock. Toward the summit the character gradually changes, the rock becomes lighter, more dense, and breaks with a broad conchoidal fracture. The outcrop at the top has a nearly white color. Down the slope, in the direction of Fivemile Creek, the character changes again, the phenocrysts of feldspar become more numerous, and the rock has a perceptibly granular appearance, which indicates that it is crystalline. At times the rock forming the débris heaps which represent the broken-down outcrops are more crystalline, appear richer in feldspar phenocrysts, and more basic than the rhyolite. These rocks may occur as dikes, but are really believed to be drawn out, included masses, such as occur in the granite.

All of these changes are accompanied by corresponding variations in structure and crystallization, as brought out by study with the microscope. Again, in the glacial drift on the lower slopes of the hills, varieties of the rhyolite occur which, although the proof is positive that they came from the Castle Mountain effusions, are not exactly similar to any of the masses now in place. It is often surprising to see how fresh the material in these glacial pebbles is, while the outcrops from which they came (which can in a few cases be identified) have been deeply altered by the elements.

In structure there are all gradations from such rocks as those mentioned above to a pitchstone glass, and in crystallization from holocrystalline through microspherulitic forms to amorphous glass. The more coarsely spherulitic or pumiceous forms which constitute so prominent a feature of the great rhyolite masses of the Yellowstone National Park to the southward have not, however, been found in this district. If they formerly existed, as they might well have, they have been swept away by erosion and glaciation.

As previously stated, there are three principal occurrences of rhyolite in the district besides the one just mentioned: the masses near the mouth of Fourmile Creek, the glassy flows occurring at the forks of Checkerboard Creek, and a great flow on upper Bonanza Creek resting on the Cretaceous strata.

LOWER FOURMILE RHYOLITE.

The mass which occurs on the right side of Fourmile Creek, forming a hill near the crossing of the road to Martinsdale and about two miles southeast of where Fourmile empties into Smith River, presents a rock of a pale-gray color on a fresh surface. It is extremely dense in texture, breaking with a conchoidal fracture. Small, rather sparsely scattered quartz and feldspar phenocrysts are to be seen, and occasional minute black dots.

Under the microscope it is found to consist of quartz, feldspar, tourmaline, and a little iron ore and zircon. The feldspar phenocrysts are fresh and unstriated. They appear to have exerted an influence on the crystallization of the groundmass, in that they are surrounded by a narrow but distinct aureole of quartz and feldspar granules, in which the latter are oriented like the phenocryst. The quartz is similar and of the usual type found in such rocks. The tourmaline occurs in small, formless shreds and patches, rather regularly scattered through the groundmass, but very insignificant in total bulk. It is of an olive-brown color and strongly pleochroic. That it is not hornblende or mica is shown by its lack of cleavage and its optical properties. The groundmass is an allotriomorphic mixture of quartz and unstriated feldspar in small, formless, interlocking grains between the larger ones, of which the more minute granules are collected in small micropoikilitic structures. This is quite similar to the Musselshell porphyry described above. The iron ore and zircon are rare. The tourmaline and occasional patches of ferritic material are believed to represent the former presence of biotite, which was destroyed during the second period of consolidation by mineralizing vapors given out on cooling. It is believed to have been biotite rather than hornblende from the fact that the former is the common ferromagnesian component in the majority of the acid rocks of the district. An analysis of the rock (No. 237) gave the following result:

Analysis of rhyolite from Fourmile Creek.

[By L. V. Pirsson.]

	Per cent.
SiO_2	74.90
TiO_2	.15
Al_2O_3	13.64
Fe_2O_3	.66
FeO	.50
MnO	Trace.
MgO	Trace.
CaO	.61
Na_2O	4.22
K_2O	4.64
Li_2O	Trace.
H_2O	.33
Total	99.65
Sp. gr.	2.61

This analysis is almost identical with that of the quartz-tourmaline-porphyry previously described; it would, indeed, make an excellent duplicate of it. It is also closely similar to that of the normal variety of quartz-porphyry given on page 99. It shows the same even relations of soda to potash exhibited by the majority of the acid rocks of Castle Mountain, and is, therefore, a contemporaneous phase of the eruptive magma. The prevailing feldspar must be a soda-orthoclase, since no striated feldspars have been observed. In structure, minerals, texture, degree of crystallization, and chemical composition this rock is precisely identical with the common type of quartz-porphyries of the district, and in a natural system of classification would be called such, though it has been found convenient to describe it here under the head of the effusive rhyolites.

The rock composing the small masses which rest as caps on the limestone forming the north side of the canyon of Smith River below the mouth of Fourmile Creek, is in general quite similar to the above, though lacking in phenocrysts. It also contains tourmaline. The outcrops are noticeable on account of their white color.

About a mile north of the main mass mentioned above, and near the mouth of Fivemile Creek, there is a small cap of rhyolite on the point of the hill. It is in connection with basaltic breccias at this point, as mentioned on page 73. The rock is much brecciated, and under the microscope is seen to consist of a glass, colored reddish-brown by a large amount of ferritic material distributed through it. It is much cracked and the cracks are filled with secondary calcite deposits. The glass shows a considerable amount of feldspar microlites dispersed through it, which polarize very feebly. Other areas show the feeblest possible aggregate polarization, and may be portions where devitrification is going on. Collections of opacite material may represent some former ferromagnesian mineral. No crystals which could be called phenocrysts were observed.

FOURMILE RHYOLITE.

The rhyolite on the right side of the canyon of Fourmile Creek, which forms the high hill previously mentioned, varies in the different occurrences. The talus slope and outcrops furnish a lithoidal rhyolite, with lines of flow structure which appear under the microscope very similar to many typical and well-known occurrences of parallel rocks, such as the felsophyre from Elfdalen in Sweden, or that from Tharandt in Saxony. With low powers, in ordinary light, the section has a structure recalling many woods with knotted, wavy, sinuous grain, used for ornamental purposes. This appearance is caused by alternating bands of material with different colors and structures. One set appears reddish, being highly charged with ferritic material, while the other is grayish, from collection of the ferritic material through crystallizing processes into excessively minute ore grains. In their interrelations these bands display great variety; they knot and wind and twist around and pass one another; at times they lie quite parallel in long strings, and at other times they bend up abruptly or break off in cuspidate forms. Around the phenocrysts, which are quartz and unstriated feldspar, they always bulge out, as wood fibers pass around a knot. The phenocrysts are nearly always broken and cracked; often, indeed, only detached angular fragments are seen, and at times a quartz which has been completely cracked up is distributed in a heap of chips along the plane of flowage, appearing somewhat like a mass of secondary quartz filling a cavity. The whole phenomenon, in short, is that caused by an excessively tough, viscid mass pulling and stringing along with great force, caused by its own enormous weight. With higher powers, in polarized light, it is seen that the lighter-colored gray bands are finely crystalline, a mixture of quartz and feldspar in allotriomorphic structure. Darker-gray bands give only a cryptocrystalline polarization, while the yellowish bands are apparently the much-discussed microfelsite; that is, while they do not act on polarized light by the highest powers, they are granular, composed of scales, shreds, fibers, etc., of a brownish color. The writers are inclined to believe that, in the present case at least, they represent collections of globulitic ferrite material in the glass, and that in the grayish bands, where the glass itself has actually partially crystallized into minute particles of quartz and feldspar, this has further agglomerated the ferrite particles into minute grains of iron ore.

At other times the grayish bands are composed of rows and masses of microspherulites with negative interference cross; or again they are formed of fibers not arranged in spherulites, but in parallel growths, arranged perpendicularly to the length of the band—i. e., to the plane of flowage—or in fan-shaped forms. In these cases there is always a double set in each band, and often between them are small grains of quartz, or they are separated by a layer of crystalline granular quartz and feldspar. The fibers are generally negative in their optical orientation, and in this case may be safely referred to feldspar; but occasionally they are positive, and may be either quartz or feldspar, as shown by Cross[1] and Iddings.[2]

Toward the top of the hill the dense rock encountered in the outcrops does not possess the banded structure just described; nevertheless, in thin section the lines of flowage are quite as plainly shown by the granules of iron ore, which represent in ordinary light a sort of dotted drawing of these flow structures. In polarized light the same microspherulitic layers are found, but the material which separates them is no longer glassy, polarizing with low powers with a uniform gray tone, which, with the highest objectives, is found to be due to a minute cryptocrystalline aggregate. It resembles the sections of slates formed by the deposition of excessively fine silt. It has all the appearance of the devitrification of a glassy base.

DEVITRIFICATION.

At the present day many petrographers are inclined to attribute to devitrification of an originally glassy base all those fine-grained groundmasses in rhyolites which consist of an allotriomorphic mixture of quartz and feldspar, and especially those which show also spherulitic and other structures which form in rapidly cooling igneous magmas. This devitrification is supposed to be a secondary process, generally due to weathering, and to be distinguished from original crystallization.

In many cases it is not always clear in exactly what sense the word "secondary" is used. Of course, strictly speaking, there is no moment when a rock remains absolutely passive, unacted upon, unchanging. From the moment that crystallization sets in until, decayed, the rock is turned into soil, processes of various kinds are acting upon it; and in this sense there is no time boundary between processes original and processes secondary. Still, practically, we may say that original rock-making processes cease when the molecules lose the motion derived from the heated mass and come to rest either as a stiffened glass or in crystal symmetry.

The question of solidity must also be considered. Of course, when the molecules of a body fall into symmetrical, crystal position, it then becomes solid and generally rigid. This is not the case with acid glasses, however, for with them no exact line dividing the liquid from

[1] Bull. Philos. Soc. Washington, Vol. XI, 1891, pp. 426–427.
[2] Ibid., p. 457.

fluid state can be drawn, and rigidity or capability of movement seems to be, in such cooling material, largely a function of time and mass.

Again, spherulites are undoubtedly bodies which form very rapidly when the conditions of the cooling fluid are right for their formation, and this, as remarked by Cross,[1] seems to depend upon a certain viscosity of the medium. Anyone who has studied the phenomena of crystal growth in solutions will recall how rapidly crystallization takes place in those which are heavily saturated, when the temperature reaches the proper stage.

There is in the writers' possession a mass of glass, spherulite-filled, which resulted from the accidental breakage of a Pennsylvania glass furnace a few years ago. Similar specimens from Staffordshire, England, are seen in the museums. The interesting feature with respect to this specimen is that the spherulites, which consist of an undetermined white mineral and vary in size from small shot to a musket ball, are drawn out into lines of flowage, sometimes, indeed, deformed by its dragging effect. The glass thus consists of nonhomogeneous layers, some pure glass, others glassy and filled with spherulites, and thus presents a perfect analogy to the glassy rhyolites. But we know that these spherulites were not present in the molten mass in the furnace and that they formed before flowage of the material ceased, and therefore their production must have been a relatively rapid one.

But if there is enough fluidity left for flowage after spherulites have formed in acid glasses, there is also enough left for crystallization. Moreover, the force of chemical affinity, acting within limited distances, is the most powerful one with which we are acquainted. It is easy to imagine that a resultant crystallization might convert the remaining glassy base, still hot and enormously viscid, into a microcrystalline allotriomorphic mixture of quartz and feldspar.

Thus we might have the formation of spherulites and other forms of rapid growth that occur in rhyolites, and then, as the mass became too viscid for their formation, a further fine-grained crystallization, all as the result of continuous processes in nowise to be regarded as secondary.

Though they can not definitely prove the fact, the authors believe this to have been the case at Castle Mountain in occurrences of the rhyolites under discussion. It is in nowise intended by this to deny the fact that glasses become devitrified by secondary processes of weathering, etc.; we have, indeed, positive evidence, in the devitrification of artificial glass, that it does occur by such means. It is intended only to point out that the occurrence of spherulites, etc., in rhyolites with fine-grained holocrystalline bases does not necessarily imply devitrification by weathering, as seems generally accepted at present.

At the summit of the rhyolite-capped hill at the lower forks of Fourmile Creek the rock becomes more coarsely crystalline, passing, in fact,

[1] Bull. Philos. Soc. Washington, Vol. XI, p. 433, June, 1891.

into a quartz-porphyry with a microgranitic groundmass. In the direction of Fivemile Creek the rock heaps at times consist of material very similar to the dikes of felsite and quartz-free porphyries already mentioned. Quartz is found only in the groundmass, and then often sparingly. The orthoclase phenocrysts are larger and much more numerous than in the rhyolite just described; they contain intergrown albite lamellæ, so frequently seen in the feldspars of eleolite-syenite. Biotite was formerly present, but is nearly always altered to ferruginous products. Such variations bear a close analogy to the felsite dikes and to the included masses in the granite. The transition from the rhyolite was found in one case to be gradual and not abrupt, as might be expected from the presence of a dike, and they are regarded as partly differentiated masses occurring in the rhyolite, though the outcrops are not sufficient to decide the question definitely.

RHYOLITE OF CHECKERBOARD CREEK.

The geologic occurrence and general appearance of the masses of glassy rhyolite through which the forks of Checkerboard Creek have cut their way have been described on page 71. A typical specimen of this rock shows a dense semivitreous-looking groundmass, of a brownish-gray color, embedded in which are irregular-shaped fragments of a black, glassy pitchstone resembling anthracite coal. These fragments are of all sizes, from little pieces like fine grains of sand, which thickly crowd the gray-brown mass, to chunks several inches long. Besides these there are many small fragments of reddened Belt shales and of gray limestone. All these materials are arranged so that they indicate the lines of flowage, though this is not so well perceived on a hand specimen as on the rock face of the outcrops. The larger fragments of black pitchstone have a pronounced lamination along the flowage planes, and this is shared to a lesser degree by the entire rock mass. The rock is also much cracked and very brittle, making it difficult to procure good specimens.

Under the microscope the black fragments of pitchstone, which make up a quarter to a third or even more of the rock, are found to consist of a clear, colorless glass, peppered through with minute microlitic grains of iron ore. At times these reveal a flow structure in the glass. Generally these glass fragments are sharply bounded against the mass in which they lie, but in a few instances the boundary is indefinite and a partial remelting took place. The evidence gained from a study of these fragments shows that though they were too viscous and cold to be remelted, they still possessed plasticity enough to be deformed in their shapes by the dragging motion of the flowage, and also to become laminated.

An analysis of a good clear piece of this glass gave the result shown by the following figures:

Analysis of rhyolite from Checkerboard Creek.

[By L. V. Pirsson.]

	Per cent.
SiO_2	72.56
TiO_2	.20
Al_2O_3	12.33
Fe_2O_3	.80
FeO	.82
MnO	Trace.
MgO	Trace.
CaO	Trace.
Na_2O	5.36
K_2O	3.08
Li_2O	Trace.
H_2O	4.59
Total	99.74
Sp. gr	2.37

That no minerals except iron ore were observed in this pitchstone is due in part to the almost total lack of lime and magnesia. The preponderance of soda over potash is a marked feature of the analysis; in this respect this rock stands alone among the acid effusives and intrusives of the district. Disregarding the water and comparing the silica, alumina, and total alkalies with those of the other acid rocks, the similarity is seen to be marked and shows the common genesis of the types.

The grayish-brown material in which these fragments lie does not polarize, neither does it appear definitely glassy. With the highest powers of the microscope there appear myriads of tiny globulites, which are believed to be iron ore, and these and the decomposition products resulting in places from their hydration, mingled with a glassy base, are believed to be the composition of this material. It shows pronounced flow structures, and contains green hornblende, plagioclase, unstriated feldspar, and quartz as rather infrequent phenocrysts, all of which are more or less cracked and appear at times in angular fragments.

The inclusions of limestone are generally but little altered. There has been little or no absorption of their material by the magma and no new minerals have been produced in them. They are generally slightly marmorized. The fragments of shale also appear little altered. More interesting are a few inclusions of holocrystalline igneous rocks that appear to have been torn off and taken up during the upward movement of the magma. One of these shows a mica-trachyte inclining to andesite, lath-shaped feldspars in trachytic structure, a considerable proportion of which are plagioclase. Mixed with these are idiomorphic biotites and some iron ore. Several fragments of this rock were seen, but always very small, about 1 millimeter across. Other inclusions are those of a quartz-porphyry. All these fragments are angular and clearly enallogenetic.[1]

No analysis was attempted of the grayish-brown base or of the rock as a whole, owing to the impossibility of obtaining even moderately homogeneous material. The analysis of the clear pitchstone glass given above must, however, represent the rock as a whole, since it was clearly a portion of the flow that, stiffening first, was cracked up, rolled under, and kneaded through the mass.

From the foregoing description it will be seen that these rock masses on upper Checkerboard Creek present the remains of a large lava flow, the material composing which is a very fresh and typical rhyolitic flow breccia.

RHYOLITE OF UPPER BONANZA CREEK.

The large flow, through the eastern portion of which Bonanza Creek has cut a deep drainage channel into the upturned Cretaceous quartzites on which it rests, presents a rock which megascopically differs in habit from the rocks previously described.

A typical specimen shows an ocher-yellow to brown-colored, dense, crackly groundmass, in which lie imbedded numerous white feldspar phenocrysts averaging 2 to 3 millimeters in diameter, with somewhat less numerous ones of quartz. The base is more or less altered, and at times somewhat earthy. Its yellowish color and numerous phenocrysts are its chief characteristics. Fragments collected from the glacial drift on lower Bonanza Creek are very fresh, however, and do not differ materially, except in a darker gray color, from specimens obtained from other parts of the district.

Under the microscope the sections appear like varieties previously described. The groundmass is always very fine granular crystalline, sometimes tending toward a micropoikilitic structure, sometimes microgranitoid. The phenocrysts are orthoclase in large crystals, and there is a lesser amount of an acid plagioclase, always quite idiomorphic, and quartz which has all the characteristics that obtain in such rocks. The ferromagnesian mineral is a brown biotite, generally greatly altered to ferruginous decomposition products, sometimes to white mica, with separation of iron ore. The groundmass is more or less stained with limonite, which gives the rock its yellowish color.

In the denser material from the glacial drift, which was evidently swept from higher levels in the mass, the groundmass shows a cryptocrystalline polarization and appears like a devitrified glass. The micas, which are altered to muscovite and iron ore, and the other phenocrysts are arranged in lines which show flow structure.

[1]Lacroix: Les enclaves des roches volcaniques: Ann. Acad. de Macon, Vol. X, 1893, p. 8.

The microscopical study of the sections shows so close an agreement with the other rhyolites of the district that no further remarks are necessary.

BRECCIAS AND TUFFS.

The breccias, which occur so frequently on the foothills drained by the head waters of Checkerboard and Fivemile creeks, are almost uniformly of one type. They consist of fragments and angular masses of all sizes, of various limestones, Belt shales, and, less commonly, igneous rocks held together by a light-yellowish to grayish cement, which appears greatly kaolinized and is somewhat cavernous from the decay of former inclusions. The proportion of inclusions to cement is very large. Sometimes the fragments are several inches long, but in the main they are comminuted Belt shales, which pepper the mass through and through.

The microscopical examination of such material affords little that is conclusive. The inclusions seem to be little altered. In the cement are found broken quartz crystals, fragments of feldspar, and occasional hornblendes or decayed micas. The cementing material appears greatly altered and seems to be silicified as well. Stringers and veins of quartz run through and along planes which may represent bedding planes of the ash or lamination planes of an original glassy fragment? Much secondary silica is deposited in fibers, and these seem to be of chalcedony. Much of the material is extremely fine and indeterminable.

From what has been already stated concerning the occurrence of a flow breccia, it is evident that cases may arise in which, if the material composing the cement is as greatly altered as in the present case, it may be doubtful whether one has to deal with an originally explosive air breccia or with a flow breccia.

The material composing the breccia deposits on Fourmile Creek and on which the upper rhyolite hill rests is much better preserved. There are the same sedimentary fragments, but the cement joining them, which has a grayish color, is full of lapilli, shown by their shape, etc. It contains numerous fragments of quartz-porphyry and other igneous rocks, which are, however, as a rule very small in size. Broken crystals of quartz, feldspar, hornblende, and mica leaves are scattered through the mass. The lapilli were many of them once glassy and show flow structures, which end abruptly against the adjoining portions.

RHYOLITIC TUFFS.

The great quantity of this material and the difficulty of properly delimiting it have been mentioned in Chapter V. The best exposure, which is illustrated in Pl. XI, is composed of a brownish, somewhat friable material, of nearly the consistency of chalk and as easily cut with the knife. Close examination will enable one to detect an occasional crystalline face or cleavage of some mineral fragment in this soft brown background.

Under the microscope the tuff is seen to be more or less decomposed. It consists of a brownish material which does not act upon polarized light, scattered through which are fragments of pumiceous glass. These are clear and transparent, of the well-known lune and cuspidate shaped forms, and at times consisting of short sections of strings pulled out by the viscous material, similar to the well-known Pele's hair. When examined with high powers these short pieces are often seen to contain a core not homogeneous with the rest, which has also been pulled out. They then appear at times strangely vermicular. Such pieces occur much more rarely than the well-known cuspidate forms. Numerous minute, broken fragments of quartz, plagioclase, sanidine, and green hornblende occur.

Occasionally there occur also brownish fragments, which are undoubtedly those of excessively comminuted Belt shales. The result of an analysis of this tuff is shown in the following table, column A:

Analysis of tuff from Checkerboard Creek.

[By L. V. Pirsson.]

	A.	B.
	Per cent.	*Per cent.*
SiO_2	61.21	68.28
TiO_2	.56	....
Al_2O_3	15.67	17.48
Fe_2O_3	4.06	4.53
FeO	.62	.69
MnO	.10	....
MgO	1.58	1.76
CaO	2.18	2.43
Na_2O	1.57	1.76
K_2O	2.75	3.07
Li_2O	Trace.	....
H_2O	10.20	....
Total	100.50	100.00

The large amount of water is especially noticeable, and shows that considerably more than could possibly be in the glass must be present, and undoubtedly much kaolin is also present. If we disregard the water and reduce the main oxides to 100 per cent we obtain the results given in column B. This does not show a composition exactly like that of the acid rocks previously described; but, on the other hand, the figures are such as should be expected when it is recalled that a considerable portion of alkalies, especially soda, would be lost by processes of kaolinization, which would cause the water to rise correspondingly; and the high alumina may also be partly explained by this and by the admixture of Belt shales. So far, then, as the chemical composition is concerned, we are warranted in referring these tuff deposits to the rhyolitic outbursts, with which, indeed, their geologic position and mode of occurrence most clearly agree.

BASALTS.

These rocks possess the usual dense black appearance so commonly a feature of basalts wherever found. The tops of the flows are more or less vesicular, grading into compact material as one descends over the outcrops toward the bottom of the flows, and a progressive increase in crystallization and granularity accompanies the change.

They are all, however, fine-grained rocks in which phenocrysts of olivine are common, while those of augite are rare.. Under the microscope a typical and fresh specimen taken from the lava flow of Volcano Butte, near the mouth of Fivemile Creek, shows a structure consisting of lath-shaped plagioclase mixed with granular pyroxene. The broad laths of feldspar with the augite filled into the interspaces suggest at times an approach to ophitic structure of diabases, though it is never exactly attained. Olivine in good-sized, idiomorphic crystals, solely of the first generation, appears freely scattered through this. It is generally very fresh, though at times a little serpentinized along cleavage cracks.

The augite, of the usual basaltic type, appears in small grains, but never in large phenocrysts. The feldspar is fresh, and its extinction angle, rising to 35°, shows it to be labradorite. Iron ore and apatite are also present. Occasional small patches in the angular interspaces between the feldspars are of a brownish color and are filled with globulitic material. They represent partially devitrified glass. Occasionally other interspaces are filled with a mineral which is colorless and transparent, of extremely low single refraction, and of a double refraction so low that it appears at times isotropic. Its double refraction is best studied under the sensitive tint. It does not carry any interpositions or included microlites, and its form is determined by the shape of the space in which it is found. It is therefore not leucite, and the difference between it and those spaces which are clearly filled with glass, together with its lack of color and general anisotropic character, show that it is not a glass. It may be nephelite, or a zeolite resembling analcite, but with optical anomalies. It is present in too small amount and too minute masses for any satisfactory decision. The rock appears to be very fresh, and the amount of water shown by the analysis would seem to indicate the latter as the more probable of the two. It is also to be noted that where the ends of the feldspar laths project into this mineral they are not sharp and clear in outline, but appear rounded, corroded, with little bays eaten into them. The low percentage of alumina shown by the analysis seems to be the only argument against the presence of a high alkali-alumina silicate.

An interesting feature is the occasional appearance of sporadic quartz grains. Their occurrence in basalts has been so fully discussed by Diller, Iddings, and Andreæ, [1] and more recently in such detail and

[1] Iddings: Am. Jour. Sci., Vol. XXXVI, 1888, p. 208; Bull. U. S. Geol. Survey No. 66, 1890. Diller: Am. Jour. Sci., Vol. XXXIII, 1887, p. 45; Bull. U. S. Geol. Survey No. 79, 1891. Andreæ, Zeitschr. Deutsch., geol. Gesell. 1892, p. 824.

with such beautiful plates by Lacroix,[1] that the present example adds but little to what has already been observed. The grains are corroded, cracked, and surrounded by the usual corona of pyroxene, which is precisely similar in all details to the typical cases mentioned by Lacroix. They have been also at times entirely melted, and their former presence is indicated by the pyroxene grouping. No inclusions, vitreous or gaseous, appear in the quartz, which is pure and limpid, a fact which seems to be contrary to the general case. In regard to the question of the primary origin of these sporadic quartz grains, the writers can add nothing to what has already been said, from any facts which this occurrence affords. Since the grains have been partially absorbed, however, it is evident that whether they were foreign substances caught up by the magma, as thought by Lacroix, or were primary secretions in the molten fluid, as held by Iddings, the subsequent phenomena or crystallizations around them would be similar, and these phenomena alone are therefore not sufficient to decide the question.

In the present case their number is too infrequent to exercise any influence on the chemical composition of the rock, which was found by analysis to be as follows:

Analysis of basalt from Volcano Butte.

[By L. V. Pirsson.]

	Per cent.
SiO_2	46.52
TiO_2	2.98
X	.73
Al_2O_3	10.48
Fe_2O_3	4.40
FeO	7.79
MnO	.11
MgO	10.58
CaO	9.49
Na_2O	3.12
K_2O	1.55
Li_2O	Trace.
H_2O	1.79
P_2O_5	.83
CO_2	Trace.
Total	100.37
Sp. gr	2.99

The symbol X refers to those earths which, obtained with titanic acid, are not dissolved by cold water after a bisulphate fusion. They may consist of tantalic and niobic acids and are naturally more or less impure, with traces of zirconia, titanic acid, etc. As they exercise no influence on the petrographical questions for which the analysis was made, no attempt has been made to separate and determine them.

[1] Les enclaves des roches volcaniques: Ann. Acad. Macon, Vol. X, 1893, p. 17.

The large amount of titanic acid points clearly to ilmenite as being the chief iron ore. The trace of carbonic acid is due to a slight amount of infiltrated calcite, coming probably from the waters of Smith River, which drain the limestone plateau of the Little Belt range to the northward, and from those of Fivemile Creek. The phosphoric acid is, of course, from apatite, which is present in considerable amount. The low percentage of alumina and the large amounts of lime and magnesia are characteristic features of the above analysis, and they serve to explain the abundance of olivine and pyroxene in the rock. The low percentage of alumina, together with that of the silica, also indicates that it can not be a very feldspathic rock. Chemically it is closely related to the lamprophyric dike rocks whose analyses have been already given and which will be found compared on page 136, and in some respects is intermediate between them. The writers believe it to represent the same general stage of differentiation of the Castle Mountain magma, and that had it solidified in dike form it would have been a rock of pronounced lamprophyric character.

The pumiceous, scoriaceous material which composes so large a part of Volcano Butte is too greatly altered for petrographic examination, but the more solid portion of the upper end of the lava streams which terminate here is quite similar to the above except for its much finer grain in the groundmass. The size of the olivine phenocrysts remains, however, the same as would naturally be expected. It also contains some brown biotite, a mineral not observed in the coarser-grained forms. The constituents also show, by a more or less parallel and oriented arrangement, that some of them had formed previous to or during the flow, so that they were arranged by it.

The inclusions of Belt shales, which are in places quite thickly distributed, do not seem to be greatly altered as a rule. Smaller ones, however, contain a mineral in grains without form, but of high single and double refraction. They are too small to be determined with certainty, but appear like pyroxene.

The other basalt flows which occur in the northern portion of the district are quite similar in type to that already described. They show at times a conversion of the olivine into the red mineral to which Lawson[1] has given the name of iddingsite, or rather, one should say, into a red mineral corresponding in the main to the description of iddingsite. In the present case it is, however, clearly a decomposition or alteration product of olivine, and precisely similar to an occurrence previously described.[2] As the material is not of such a nature as to furnish this mineral in quantity or in quality proper for analytical investigation, it would be useless to speculate further upon its exact nature. It is quite possible that it is not the iddingsite of Lawson at all.

[1] Geol. Camelo Bay: Bull. Geol. Dept. Univ. Cal., Vol. I, 1893, p. 30.
[2] Am. Jour. Sci., 3d series, Vol. XLV, 1893, p. 381.

CHAPTER VIII.

GENERAL PETROLOGY OF THE CASTLE MOUNTAIN DISTRICT.

In the foregoing chapters it has been shown that the igneous rocks of Castle Mountain all belong to one center of eruptive activity. Taken as a whole, they constitute a unit, separated geologically and petrologically from other neighboring centers of igneous action in this portion of the Rocky Mountain region. A study of their geologic disposition and mode of occurrence must convince the observer that no matter how diversified their mineral nature, no matter how different their chemical composition, they have all had a common origin. On no other supposition could we reasonably explain the intimate association of such varied types.

The fact that from the same center of activity rocks varying both chemically and minerally may arise, has, at the present time, been shown in so many different occurrences that it is only necessary to call attention to it in passing. Admitting, then, as well grounded, the assumption that the Castle Mountain rocks are varied phases of a single molten mass below, it remains to inquire what bearing the facts observed have upon the general question of the differentiation of molten magmas and the origin of igneous rocks.

It is to be clearly noted at the outset that in the comparative study of the rocks of any district, in the endeavor to trace their relationships and to determine the laws of their formation, the student is met at the very beginning by a great and insuperable difficulty. The facts observed and the theories advanced must result from an examination of what is, comparatively speaking, the surface alone. Whether the locus of fusion and sources of eruptive material are deeply seated, as claimed by some, or are in the superficial crust of the earth, as argued by others, is, petrologically speaking, of little moment, since the volume of material exposed at the surface or concerning which safe inferences may be drawn, is, or may be, minute compared with what may exist below, even in the relatively superficial crust. Thus our results can never be quantitative, but must always be qualitative, and possibly even then not complete. It is true that Brögger, in his striking work on the basic eruptive rocks of Gran,[1] has arrived at some results which are quantitative, but the localities where such work may be performed are necessarily limited, and for the present a certain reserve will naturally

[1] Quart. Jour. Geol. Soc. London, Vol. L, 1894, p. 15.

be held until concurrent facts from a number of such districts show the views held by Brögger and others to be of general application.

The chemical examination of the rocks of any distinct locality does, however, afford data for qualitative results of magmatic variation, which are of extreme value in showing how far and in what directions such variation has taken place. It is necessary to remember only that such results are qualitative, not quantitative, a fact often overlooked by theoretical petrologists.

It is unnecessary to detail here the various theories that have been held by different geologists as to the origin and cause of the variation of igneous rocks. They have been admirably reviewed with great fullness and detail by Hague[1] and by Iddings[2]. As stated above, the view that is commonly held at the present time is that the variations observed at any eruptive center are due to the differentiation of a single, originally homogeneous molten mass. This theory, as extended by some writers, further supposes that the mass has in the beginning a composition in type intermediate between the acid and the basic rocks—that it is similar to an andesitic lava. As the differentiation progresses the iron, magnesia, and in great part the lime molecules are concentrated in certain areas, while the silica, alumina, and alkalies are thereby increased in the remaining portions. During the process of concentration the oxides are supposed by some to be in a state of combination as definite mineral molecules, while by others they are supposed to be in a dissociated condition. Recently the volcanologist, Johnson-Lavis,[3] has propounded a theory by which the variations observed at a given center are referred to the solvent action of a magma on the containing crust walls; that is, as the magma rises in the conduit or remains molten in a cavity its composition will change by the absorption of the country rock. Various obstacles to this view might be pointed out, and on the chemical side none seems to present greater difficulties than a consideration of the alkalies. For, considering the theory as true, it is evident that if we deal with an originally trachytic magma, suggested by Johnson-Lavis, any addition of country rock must tend to lower the alkali content. Therefore, in a center ejecting phonolites with 15 per cent of alkalies, this must be supposed to be the original magma. Since these are accompanied, however, by very basic rocks with low alkalies, it appears that the amount of dilution by foreign material would have to be enormously beyond what we may well consider possible. The extreme range of alkalies at Castle Mountain is, in molecular proportions, as 125:50; in percentages, 9:4.25; and to reduce the former to the latter would require, supposing the most favorable, though improbable, case, that the absorbed material should contain no alkalies and that the magma should absorb somewhat more than its own weight of country rock.

[1] Geology of the Eureka District, Nevada: Mon. U. S. Geol. Survey, Vol. XX, 1893.
[2] Origin of igneous rocks: Bull. Philos. Soc. Washington, Vol. XII, 1892, pp. 89-214.
[3] Natural Science, Vol. IV, Feb., 1894.

The theory would also necessarily require that the acid magma should give evidence of having possessed the greatest amount of heat, while the state of the included foreign fragments at Castle Mountain, as pointed out in the preceding chapter, evinces the contrary; observations in agreement with those of Lacroix.[1] Finally, as pointed out by the author himself,[2] we should expect that in case an igneous rock mass varied locally it would do so in accordance with the more acid or basic nature of the enveloping rock, while in the case of the intruded diorite area at Castle Mountain exactly the contrary is to be observed; the center of the stock is a diorite with 56 per cent of silica, which grows steadily more acid toward the periphery, till at the contact it has the facies of a very acid quartz-porphyrite, though intruded into limestones and very basic shales.

Quite recently Bäckström[3] has proposed a modification of the theory of differentiation by which this process shall depend on the separation, at a certain stage of cooling, of the originally homogeneous liquid magma into two or more miscible fluids which form a kind of emulsion. To support this view he adduces the behavior of certain artificially formed liquids and presents arguments against the theory which causes differentiation to depend on dissociated molecular diffusion or crystal separation. This view has been previously referred to.

It is now in order to consider what bearing the facts brought out by the study of the Castle Mountain rocks may have on theoretical petrology. For this purpose it will be necessary to consider the analyses, and for convenience they are presented together in the accompanying table on page 135.

[1] Les enclaves des roches volcaniques.
[2] Loc. cit., p. 139.
[3] Jour. of Geol., Chicago, Vol. I, 1893, p. 773.

Table of analyses of Castle Mountain rocks.

[Analyses made by L. V. Pirsson.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
SiO_2	74.90	74.82	72.48	72.38	72.56	72.88	71.67	65.87	61.21	61.87	56.80	46.52	45.15	42.46
TiO_2......	.15	.25	.32	.10	.20	.45	.10	.37	.56	.87	.46	2.98	2.80	2.47
X.........	......	......	......	......	......	......	......	......	......	......	......	.73	......	......
Al_2O_3.....	13.64	13.80	13.14	14.71	12.33	12.90	15.82	16.82	15.67	17.26	18.30	10.48	15.39	12.04
Fe_2O_3.....	.66	.37	1.66	1.09	.80	.74	1.18	1.58	4.06	2.35	1.64	4.40	2.76	3.19
FeO	.50	.30	1.02	.82	.82	1.05	.35	1.23	.62	2.43	5.58	7.79	5.64	5.34
MnO......	Tr.	Tr.	Tr.	Tr.	Tr.	.05	Tr.	Tr.	.10	.03	Tr.	.11	.14	.16
MgO......	Tr.	.10	.15	.70	Tr.	.75	.13	1.54	1.58	1.82	3.63	10.58	6.38	12.40
CaO	.61	.17	1.04	.67	Tr.	.81	.25	2.65	2.18	3.23	5.31	9.49	8.83	12.14
Na_2O	4.22	4.33	4.22	4.28	5.36	3.72	4.46	4.72	1.57	5.18	4.35	3.12	2.67	1.21
K_2O	4.64	4.81	4.88	4.15	3.08	5.03	4.45	3.15	2.75	3.83	3.28	1.55	2.77	2.68
Li_2O	Tr.	Tr.	Tr.	Tr.	......	......	......	......	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
H_2O	.33	.83	.42	.92	4.59	1.22	1.21	1.43	10.20	1.07	.53	1.79	2.85	4.03
CO_2.......	......	......	......	......	......	......	......	......	......	......	......	Tr.	4.27	.55
P_2O_5	......	......	......	......	......	......	......	Tr.	......	Tr.	Tr.	.83	.56	.84
Total ..	99.65	99.78	99.33	99.82	99.74	99.60	99.62	99.36	100.50	99.94	99.93	100.37	100.21	99.51
Sp. gr.....	2.61	2.59	2.62	2.61	2.37	2.64	2.60	2.62	......	2.67	2.83	2.99	2.70	2.94

I. Rhyolite between Fourmile and Fivemile creeks, near Smith River.
II. Quartz-tourmaline-porphyry, upper Fourmile Creek.
III. Granite, Elk Peak.
IV. Quartz-porphyry sheet, ridge between Fourmile and Checkerboard creeks.
V. Rhyolite-pitchstone, forks of Checkerboard Creek.
VI. Aplitic granite dike cutting diorite between Blackhawk and Robinson.
VII. Quartz-porphyry, Musselshell Canyon.
VIII. Feldspar-porphyry dike below Castle.
IX. Rhyolitic tuff, near the forks of Checkerboard Creek.
X. Included syenitic mass in granite, head of Cottonwood Creek.
XI. Diorite, between Blackhawk and Robinson.
XII. Basalt of Volcano Butte.
XIII. Vogesite dike, upper Fourmile Creek.
XIV. Monchiquite-like dike, west side of upper Willow Creek.

In connection with these analyses, it may be remarked that the rarer elements have been sought with care, and that they are either wanting or exist in such minute quantities that they could exercise no influence on the purpose for which these analyses have been made, and therefore they have not been determined. Of these, barium and strontium may be cited as examples, the last four rocks containing traces of them.

These analyses present several points of interest, among which the relations of silica, iron, and titanic acid may be mentioned. It will be observed that the amount of the latter oxide is closely dependent upon the iron present, and that these increase in proportion as the silica decreases. The phosphoric acid also appears to depend on the lime and magnesia, being absent, or practically so, where these are very low, and increasing with them toward the basic end of the series.

In order to better exhibit the relations of the chief rock-making oxides toward one another, they have been separated from the rarer less essential elements, and are presented by themselves in the accompanying table, reduced to 100. To compare them molecularly, a table of their molecular proportions is added.

Percentages of rock-making oxides reduced to 100.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
SiO_2	76.43	75.81	75.52	74.45	73.52	73.26	72.90	68.28	67.53	63.15	57.44	50.40	49.54	46.42
Al_2O_3	12.98	13.98	13.75	13.18	13.33	14.89	16.08	17.48	17.24	17.62	18.51	17.18	11.16	13.17
Fe_2O_3	.84	.38	.67	.75	1.68	1.10	1.20	4.53	1.62	2.40	1.66	3.08	4.68	3.49
FeO	.86	.31	.51	1.07	1.03	.83	.35	.69	1.25	2.48	5.64	6.29	8.29	5.84
MgO......	Tr.	.10	Tr.	.77	.15	.71	.13	1.76	1.57	1.85	3.67	7.12	11.26	13.56
CaO	Tr.	.17	.62	.83	1.06	.68	.25	2.43	2.71	3.30	5.35	9.86	10.10	13.27
Na_2O	5.64	4.38	4.25	3.81	4.28	4.33	4.54	1.76	4.84	5.29	4.41	2.98	3.32	1.32
K_2O	3.25	4.87	4.68	5.14	4.95	4.20	4.55	3.07	3.24	3.91	3.32	3.09	1.65	2.93

Molecular ratios of the oxides in the above analyses.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
SiO_2	1,273	1,263	1,258	1.241	1,225	1,221	1,215	1,138	1,125	1,052	957	840	825	773
Al_2O_3	126	135	133	128	130	144	156	170	167	171	179	167	108	128
FeO	21	9	15	24	21	25	20	66	38	64	85	126	187	125
MgO......	......	2	......	19	4	18	3	44	39	46	92	178	281	339
CaO	......	3	11	15	19	12	5	43	48	59	95	176	198	237
Na_2O	91	71	68	61	69	70	73	28	78	85	71	48	52	21
K_2O	34	52	50	55	53	45	48	33	34	41	35	33	18	31
Na_2O ..... K_2O ...... }	125	123	118	116	122	115	121	61	112	126	106	81	70	52

I. Pitchstone.
II. Quartz-tourmaline-porphyry.
III. Rhyolite.
IV. Aplitic granite.
V. Granite.
VI. Quartz-porphyry.
VII. Musselshell quartz-porphyry.
VIII. Rhyolitic tuff.
IX. Feldspar-porphyry.
X. Syenitic mass in granite.
XI. Diorite.
XII. Vogesite dike.
XIII. Basalt.
XIV. Monchiquite-like dike.

For the sake of simplicity the iron in the above table of molecular proportions has been calculated entirely as ferrous oxide. It will be noticed that ferric oxide does not appear to show any definite relation to alumina, while, as may be seen in the analyses, the proportion of ferrous to ferric oxides remains quite constant in the acid rocks; and then, as in the basic ones the silica falls, the proportion of ferrous over ferric rapidly increases.

In regard to the alumina, it will be noticed that it rises gradually with decreasing silica until very near the basic end, when it suddenly falls. The table of molecular proportions shows that the alkalies in sum total remain pretty constant, with slight variations until the basic end is reached, when they also fall like the alumina. In the case of No. VIII, it should be recalled from the preceding chapter that this tuff is largely mingled with shale and limestone, which tend to seriously lower the alkalies and silica and increase the alumina and bivalent oxides. Therefore, although this analysis is here included for comparison, it can not be depended on in drawing any general conclusions. It is interesting to note, in the analyses of the pitchstone, that as the alkalies are to the alumina as 1:1 and to silica as 1:10, and as magnesia and lime are wanting, the rock, if crystallized, would consist essentially of one molecule of feldspar to four of quartz, and that a little iron ore would have been the only other compound. The feldspar would be an anorthoclase or a mixture of Ab. and Or. as 2.7:1.

From the above statements it will be seen that no absolute relation exists between alumina, silica, and the alkalies, since as the silica decreases the alumina rises, and the alkalies remain about the same until the basic end is almost reached, when all fall together.

The relation of potash to soda shows some facts which are interesting to study. Iddings[1] has called attention to the fact that this relationship is characteristic for regional rock groups, and our study of the analyses of the rocks of Electric Peak, as given in his paper, shows that $K_2O:Na_2O::1:3.94$ to $1:1.79$; or, in round numbers, the ratio varies from 1:4 to 1:2; and a consideration of the twenty-one analyses given shows that the variation is most rapid near the two extremes, while between $K_2O=1$ and $Na_2O=2.8$ to 2.4 it is very gradual and embraces a majority of the analyses, thus showing for this volcanic center a tendency to the ratio expressed by $K_2O:Na_2O::1:2.6$. The same author gives a series of analyses for another eruptive center at Crandall Basin, where the $K_2O:Na_2O$ varies from 1:2.9 to 1:1.13. Here again the variation is most rapid at the extremes, while between 2 and 1.65 it is very gradual, showing a tendency for $K_2O:Na_2O::1:1.8$.

The analyses given by Iddings are valuable for a comparative study of this nature because they show at each of the given centers the composition of a variety of rocks differing in geologic position and degree of crystallization, which latter are seen to apparently have no influence upon the relation of soda to potash. At Castle Mountain the relations are as follows:

Number of analysis.	$K_2O:Na_2O$.	Rock.
XIII	1:2.88	Basalt.
I	1:2.69	Pitchstone.
IX	1:2.41	Feldspar-porphyry dike.
X	1:2.07	Syenite mass in granite.
XI	1:2.03	Diorite.
VI	1:1.55	Quartz-porphyry sheet.
VII	1:1.52	Musselshell porphyry sheet.
XII	1:1.45	Vogesite dike.
II	1:1.36	Quartz-tourmaline-porphyry sheet.
III	1:1.36	Rhyolite.
V	1:1.30	Granite.
IV	1:1.11	Aplitic dike.
XIV	1: .68	Monchiquite-like dike.

As before, the variation is rapid around the two extremes, while in a very considerable proportion of the analyses it varies gradually

[1] Origin of igneous rocks: Bull. Philos. Soc. Washington, Vol. XII, 1892, p. 138.

between 1.55 and 1.30. Here again we see that the relation does not depend upon geologic position or coarseness of crystallization.

A consideration of the above in connection with the table of molecular proportions seems also to indicate that the relation does not depend upon the other elements present, and this theory is borne out by analyses from other localities. Thus the very basic vogesite dike has nearly the same proportions of soda and potash as the very acid rocks with which it so intimately occurs.

It will be noticed, also, that the two effusive rocks, basalt and pitchstone, standing at the acid and basic extremes, show about the same relation of potash to soda, and both differ considerably from the granite, while the rhyolite is very close to it. Again, the syenite-like mass included in the granite has a relation like that of the diorite, and both differ considerably from the granite.

From a consideration of the foregoing facts it does not appear, therefore, that the proportion of potash to soda obeys any law which can be brought into direct connection with the variation of the other elements; but, on the other hand, it would seem as if there was a tendency for a more or less definite relation to exist between them and for the most common rocks to approach this mean. This mean appears also to be characteristic for this center of eruption and to differ from neighboring ones, so far as these are known. Such analyses of Crazy Mountain rocks as are at present available indicate a higher proportion of soda to potash,[1] while that for centers farther to the southward, as mentioned by Iddings,[2] have already been given. Before this point can be considered settled, however, further analytical and petrographical work will be necessary, and the future may show that this portion of the Rocky Mountain region, embracing various centers of eruptive activity, is distinguished by a general relation of the alkalies that is characteristic, as Brögger[3] has already shown for the district of southern Norway and Bäckström[4] for Iceland. In such cases we may expect local variations in neighboring centers without disturbing the general law.[5]

In regard to the bivalent metallic oxides, iron, lime, and magnesia, it will be observed from a study of the table of molecular proportions that, with very slight irregularities, they all increase steadily and together from the most acid to the most basic end of the series.

When, from a consideration of the chemical and geologic data previously given, we endeavor to present to ourselves the composition of the original magma from which the Castle Mountain rocks have been derived by differentiation, it at once becomes evident that it must have

[1] J. E. Wolff, Petrography of the Crazy Mts.: North Trans. Survey, 1885. Ibid, Acmite Trachyte of the Crazy Mts.: Bull. Mus. Comp. Zool. Harvard Coll., Vol. XVI, 1893, No. 12.

[2] Loc. cit.

[3] Min. der Syenitpeg.: Zeitsch. f. Kryst., Vol. XVI, p. 84, 1889.

[4] Beit. z. Kennt. Island. Gest.: Geol. Föreningens Stockholm, Förhandl. Vol. XIII, 1891, p. 669.

[5] Since the above was written the authors have shown that at Yogo Peak and Square Butte, where highly differentiated magmas have been intruded, soda and potash have been differentiated with respect to each other, the potash increasing in the more basic types.

been extremely acid, if the volume of material exposed at the surface be taken as a criterion. If the whole country covered by the map should be planed down to the level of the lowest point in the district, and all of the igneous rocks fused together to a homogeneous mass, it would differ but little in composition from the granite. It would be somewhat lower in silica and a little higher in lime, iron, and magnesia, but on crystallizing it would still form a typical granite.

The huge intrusive bodies forming the cores of the Crazy Mountains to the southward are of diorite. The field work of the authors in 1893 shows that some 15 miles to the east of Castle Mountain, in the Big Belt Range, occurs an immense granitic intrusion of very similar character, and around Neihart, some 30 miles to the north, new eruptive centers with great intrusions of acid and moderately acid rocks are again encountered. In all of this area basic rocks play but an insignificant rôle, and are confined to relatively small intrusive sheets, dikes, or stocks and to thin extrusive sheets of limited area. The report of Messrs. Dana and Grinnell,[1] together with the work of Mr. Lindgren[2] and reconnaissance work by W. H. Weed, indicates a prevailing abundance of acid trachytic types of rocks in the isolated mountain groups of the country to the eastward fronting on the Great Plains region, while the medium character of the Highwood group to the northward may be seen from a paper on that region lately published by the writers.[3] If these are all assembled into a petrographical province[4] whose igneous rocks have been furnished by some huge reservoir of molten material far below, the varied types being formed by differentiation of the fluid magma contained in this reservoir, which was originally homogeneous, then the original composition of this initial mass must have been of a quite acid type, and with rather high alkali content. At Castle Mountain the material was still more acid than the probable mean of the whole district; but by a concentration of the lime, iron, and magnesia molecules—a process in some portions complete enough to entirely deprive the acid magmas of these elements—relatively small bodies of basic rocks were formed. In drawing such conclusions, however, as remarked before, it must always be borne in mind that our knowledge relates to surface exposures only.

In regard to the order of succession of the varied partial magmas at Castle Mountain, the rock exposures are not always connected in such a manner as to yield complete, definite data upon this point. It is certain, however, that the diabase is the oldest rock which appears in the district, but whether it should be directly connected with the Castle Mountain rocks in magmatic relations is at least questionable.

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[1] Rept. of a Reconnoissance from Carroll, Mont., to Yellowstone Park, Ludlow, War Dept., Washington, 1876, p. 91.

[2] Tenth Census, Vol. XV, p. 719; Proc. Cal. Acad. Sci., ser. 2, Vol. III, 1890, p. 39; Am. Jour. Sci., Vol. XLV, 1893, p. 286.

[3] Bull. Geol. Soc. Amer., Vol. VI, 1895, p. 389.

[4] Judd: Quart. Jour. Geol. Soc. London, Feb., 1886, p. 54.

The evidence seems to show that after this and the earliest of the Castle Mountain intrusions is the diorite stock, which was succeeded by the granitic intrusion, which in turn developed the outflows of rhyolite and pitchstone. Succeeding these came the outbreaks of basalt and the intrusion of basic dikes, which from evidence already given occurred at a considerably later date, when the acid rocks had become cold. These two, from their later appearance and close chemical relationships, we are inclined to consider simultaneous. So far, then, as these facts go, they conform to the general rule of the Rocky Mountain region, that the outflows became successively more differentiated into acid and basic material as they followed each other.

It can not be said that the Castle Mountain rocks, taken as a group, offer any of those marked peculiarities of minerals or structure to which Iddings[1] has given the name of "consanguinity;" the majority of them are acid rocks of very simple mineral composition, and it could scarcely be expected that they should.

Some phases of the rhyolites are extremely like those occurring in the Yellowstone Park, while others, together with the quartz-porphyries, could not be distinguished either in hand specimen or section from similar pre-Tertiary rocks occurring in Germany. The basalt appears to be of a rather common type, while the correspondence of the diabase with similar rocks has already been pointed out. The remaining types are so few in number that no general conclusion can be based upon them.

This is not, however, in any sense an argument either for or against evidences of "consanguinity" in general, since every district or individual group of rocks can not be expected to exhibit such peculiarities as will serve to distinguish it from all other districts or groups of igneous rocks. On the other hand, the preliminary study that has been made of the rocks occurring in the eruptive centers of the Little Belt Range near Neihart seems to show that they exhibit certain peculiarities of minerals and mineral association which will strongly differentiate them from the types described in this memoir, and in general from previously described rock groups; and this is also very markedly the case in the Highwood Mountains immediately to the northward.

When we consider the relation of the facts observed at Castle Mountain to the differentiation of molten magmas and the origin of igneous rocks, it at once becomes evident that this process has been a deeply seated one. There has been, it is true, some local and comparatively superficial differentiation. For example, the diorite mass grows more acid toward its contact. This is not according to the more general case where intruded masses grow more basic toward the outer edge; but cases where they reverse this order are known and have been mentioned in the literature. The less acid masses in the granite-granite-porphyry main[2] mass are also local in their formation, but in general the

[1] Bull. Philos Soc. Washington, Vol. XII, 1892, p. 128.

[2] See Min. Mitt., XII, 1891, p. 390; also, Zeitschr. f. Kryst, Vol. XVI, 1889, p. 45.

occurrences are such that the process of differentiation took place at greater depths.

No facts have been observed which would lead to the belief that differentiation has taken place by crystal separation, or by processes of crystallization, locally concentrating certain materials. On the other hand, all the facts are opposed to it. It is by no means intended by this to express a disbelief in the actuality of such processes and their capability of performing a differentiation which would give rise to rocks minerally and chemically different from a single homogeneous magma.

The fact is patent that the more the occurrences of igneous rocks are studied with reference to their origin the more evident it becomes that under the term "differentiation," as now employed, not one but several processes must be included, by any one of which, or a combination of all, varied rock types may arise from an originally homogeneous molten mass. Though "originally homogeneous" is a term very commonly employed by petrologists, as a matter of fact we have no means of knowing whether there is or has been any such thing in the sense in which this term is used. Its existence is a pure assumption, based, it is true, on good reasoning, but nevertheless an assumption.

One fact has been made patently clear by the chemical researches on rocks during the past half century, and that is that in proportion as silica and alkalies increase in a magma, the lime, magnesia, and iron sink; and that high silica, high alumina, and high alkalies go hand in hand, while high magnesia, iron, and lime and low silica go together. There are, of course, exceptions to this, but as a general law it is certainly true. Thus we should not expect to find an igneous rock with 75 per cent of silica and 25 of lime, iron, and magnesia, with alkalies and alumina practically wanting.

In general these facts seem to be due to the tendency of magmas, of whatever composition, to separate themselves into these two general products—the acid end or negative pole and the basic or positive one. The process is certainly not a stoichiometric one, and evidently a great variety of modifying causes may be also present. The original composition of the magma is of course the chief factor in determining the end products. At Castle Mountain, as already shown, it was measurably acid, and hence we find the basic products in but relatively small amount.

The exact cause that produces such a process is evidently not at present determinable. It may be, as suggested by Bäckström,[1] by processes of liquation, a method which commends itself by its simplicity, or by this in connection with other circumstances.

THE DIKE ROCKS.

The occurrence of the basic dike rocks presents several facts of general petrologic interest. One of these is the comparative rarity of such

[1] Jour. of Geol., Vol. I, 1893, p. 773.

rocks in this district as compared with that of the neighboring Crazy Mountain area, a fact previously mentioned. This rarity is evidently due in great part to the fact that the intrusions took place in strata already flexed and broken, and the tendency has been for the peripheral, fringing material to assume the position of sheets rather than dikes.

But the comparative absence of attendant basic rocks has been due much more to the extremely acid, simple character of the intruded magma, which was already, so to speak, greatly differentiated at its appearance toward the surface.

The association of the vogesite dike and intruded mass of minette is of interest in this connection, as it repeats a fact elsewhere often observed of the relation of such rocks to intruded stocks of granite. The occurrence of the minette, however, shows that such rocks are not necessarily confined to dike form, and we have, indeed, elsewhere observed in the Little Belt Mountains that if the structural relations are suitable they may appear almost entirely in the position of intruded sheets.

The occurrence of the monchiquite-like dike is interesting in this connection because such rocks have been referred to parent stocks of eleolite-syenite; yet here we find it in close geological connection with granite. The work of Brögger on the rocks of Gran, already quoted, tends to show, however, that such genetic relationships are not always invariable, although the mass of evidence tends to prove that they are at least very common.

Recently an attempt has been made[1] to formulate a general theory for the origin of lamprophyre dikes, in which the process depends on the local concentration of lime, iron, and magnesia on the borders of the magma basin below, giving rise to interior and exterior zones of more highly differentiated material than that forming the initial intrusions.

Later outbreaks of these more highly differentiated partial magmas through fissures, which may form in various ways, would give rise to rocks on the one hand more acid, more feldspathic, and on the other more basic, richer in lime, iron, and magnesia, than the earlier central masses with which they are found.

The vogesite dike on the border of the central granitic mass, with its glassy saalband, seems to the writers to furnish proof pointing to this process, while the basaltic outflows which stand intermediate in chemical composition between the vogesite and monchiquite dikes may be the results of fissures furnishing conduits to the surface for the outer basic zone of magma.

[1] L. V. Pirsson: Complementary rocks and radial dikes: Am. Jour. Sci., 3d series, Vol. L, 1895, pp. 116-121.

CHAPTER IX.

GLACIATION OF CASTLE MOUNTAIN.

Evidences of former glaciation are conspicuous on many parts of Castle Mountain. Like many other portions of the mountain region of Montana, it nourished a number of local glaciers that flowed down its flanks, filling the valleys and covering the adjacent bench lands.

The glaciation of the mountain was local in character. The surrounding region is unglaciated, and the southern limit of the two great ice sheets of the continent is over 50 miles farther north. The extent of these local ice streams, as shown by their moraines, is surprising. The mountain is relatively low, its highest point, 8,606 feet above sea level, being 2,500 feet less than the culminating peaks of the Crazy Mountains and surpassed by several summits in the neighboring Belt ranges. Yet its former glacial covering was relatively larger than that of the Crazy Mountains, while the Belt ranges were without any glaciers worthy of comment.

Bowlder moraines constitute the most important and conspicuous evidence of the former glaciation of the region. Striated rock surfaces are rarely seen, for with the exception of the granites and diorite of the mountain summit, the soft and readily eroded character of the rocks rendered their preservation impossible. The granite is the rock of which the bulk of the bowlders are formed. The craggy, castellated masses into which its peripheral portions are carved by weathering furnished abundant material, while the resistance to the ordinary processes of disintegration leaves the bowlders still intact.

A study of the mountain shows that the ice sheets had their birth in the amphitheaters and recesses that indent the sides of the mountain summit. On the mountain top itself no signs of glacial erosion were noticed. The amphitheaters still hold extensive snow banks in early summer, and the granite shows planed and rounded surfaces that are clearly the work of moving ice. The detritus that was no doubt abundant in pre-Glacial time over the summit and projecting ridges of the mountain has been entirely swept away, and the former crust of partly disintegrated and decomposed rock has been planed off.

Below these rock-carved cirques the high mountain valleys are largely occupied by the tumultuous heapings of glacial rubbish (largely overgrown by pine and spruces) that mark the declining phases of the ice. These morainal deposits do not, however, extend down the valleys and are not a continuous part of the moraines found on the lower slopes. They occur only in the mountain basins whose united rills form streams which have cut out gorges below.

In every case noted the ice gathered in and flowed down preexisting depressions in the mountain flanks. The higher parts of the ridges show no signs of glaciation, but lower down, at 7,000 feet and below, the mountain spurs expand into broad, flat areas cut out of the upturned and folded sedimentary rocks. These benches show but little drift. An occasional bowlder is seen, but the surface has been swept clean by the ice, which, filling the mountain gorges, overflowed these highland benches and ground off their irregularities of surface. Neither the Belt shale nor the Paleozoic limestones retain, however, any of the detailed evidence of such action; it is in the broader features that this work is recognizable.

Below 7,000 feet the bowlder moraines become prominent. The change from the smooth limestone areas to drift-covered, bowlder-littered bench land is quite abrupt on the southeastern side of the mountain. The northerly slopes, being cut in a variety of rocks, are less regular, and there the occurrence of morainal deposits is less striking. The lower limit of glacial drift is 5,400 feet on Alibaugh Creek, and somewhat less on the northern slopes. The areas covered by morainal deposits are shown on the geologic map.

Fine examples of bowlder moraines are crossed by the roads leading to Castle, and one is seen at the forks of Fourmile Creek. The Townsend stage road also crosses a morainal bench between Warm Spring and Alibaugh creeks. Near the town of Castle the moraines attain their best development. Ice streams, coalescing at the time of their greatest expansion, have left a mantle of drift and bowlders extending from Warm Spring Creek to Bonanza Creek that completely obscures the underlying rocks on the bench land between the creeks, and very nearly those of the valley walls. The moraine between Alibaugh and Warm Spring creeks is particularly striking. Large erratics of granite dot the surface and remind one of the glacial areas of New England. The soil consists largely of sand, formed by the disintegration of the granite bowlders, and is abundantly grassed, bringing them into strong relief. (Pl. XIII shows a photograph of this moraine-covered bench.) This moraine terminates abruptly in a steep bowlder-formed slope. The summit, where it is crossed by the road, has an elevation of 200 feet above the Cretaceous bench, and maintains its abruptness, with slightly diminished height, eastward to the mouth of Alibaugh Creek. There could be no stronger contrast than that shown along the front of this moraine between the bowlder-formed slope and the gentle monoclinal ridges eroded out of soft Livingston shales that trend at right angles to the moraine margin and disappear beneath it. The moraine summit is slightly undulatory and has a gentle rise toward the mountain.

In the vicinity of Castle, Alibaugh Valley is wide and open, and

MORAINE-COVERED BENCH SOUTH OF TOWN OF CASTLE.

glacial drift is uncommon in the valley bottom. The inclosing slopes are, however, dotted with bowlders up to 5 or 6 feet in diameter, and show successive parallel terraces with few bowlders and grassy surfaces between steep bowlder-strewn slopes. These mark successive pauses in the melting and recession of the ice. The summit of the ridge to the north is drift-covered and bowlder-strewn, quite like that of the bench lands south. While the harder rocks stand out in bold relief in the valley bottom and lower slopes, no exposures whatever are seen on the higher valley wall or summit of the bench. Alibaugh Creek flows through a narrow valley in a bowlder-choked channel in its lower course.

A short distance above the outskirts of Castle, the termination of a moraine is seen at the forks of the creek. This moraine front is represented in Pl. XIV, which shows the general character of all the morainal deposits of the mountain. It is a true terminal moraine, formed of large and small bowlders of granite, and the moraine closes in the upper mountain valley of this the chief branch of the stream. The moraine illustrated is, however, one formed during the recession of the glacier.

The abrupt upper limit of the drift is nowhere better shown than on the ridge northeast of the town of Castle. Near the Cumberland mine the summit of the flat-topped bench shows excellent exposures of the readily eroded clays and shale of the Carboniferous and overlying Mesozoic beds. A short distance eastward the drift mantle obscures all exposures.

The slopes below the rhyolite flow of Bonanza Creek show an abundance of drift, probably glacial, derived from the flow itself, but no granite was seen. The moraine forms a flat-topped ridge near the ranch on Bonanza Creek, and extends up to 6,950 feet, where it abruptly ceases. Drift of possible glacial origin was also seen at the head of Coyote Creek, but no other evidence of such an eastward extension of an ice stream was seen.

On upper Fourmile Creek the glacier formed at the head of the stream brought down granitic débris that now lies scattered over the adjacent slopes and fills the lower valley bottom. South of the road the valley of the main or easterly branch of the stream shows on the west a morainal slope, largely covered with pines, in which the white granite and porphyry bowlders show conspicuously. The east wall shows a nearly continuous straight slope of débris, encroaching upon the moraine bench of the valley bottom.

Glacial bowlders are found on all the slopes south of the road following Fourmile Creek, but the moraine is best seen near the first forks of the creek, where the drift covers the slopes of the rhyolite hill north of the road. The slopes are dimpled, having a knob and sink topography. The bowlders extend 500 feet up the slopes of the hill, showing that the ice sheet at this point still had a considerable thickness. The drift is mainly granitic, but includes some metamorphosed shale. But one bench was observed on this steep slope. Above the bowlder moraine the rocks show glaciated surfaces. The north slope of this hill consists of a succession of sloping glacial benches, showing however no bowlders, but merely small drift.

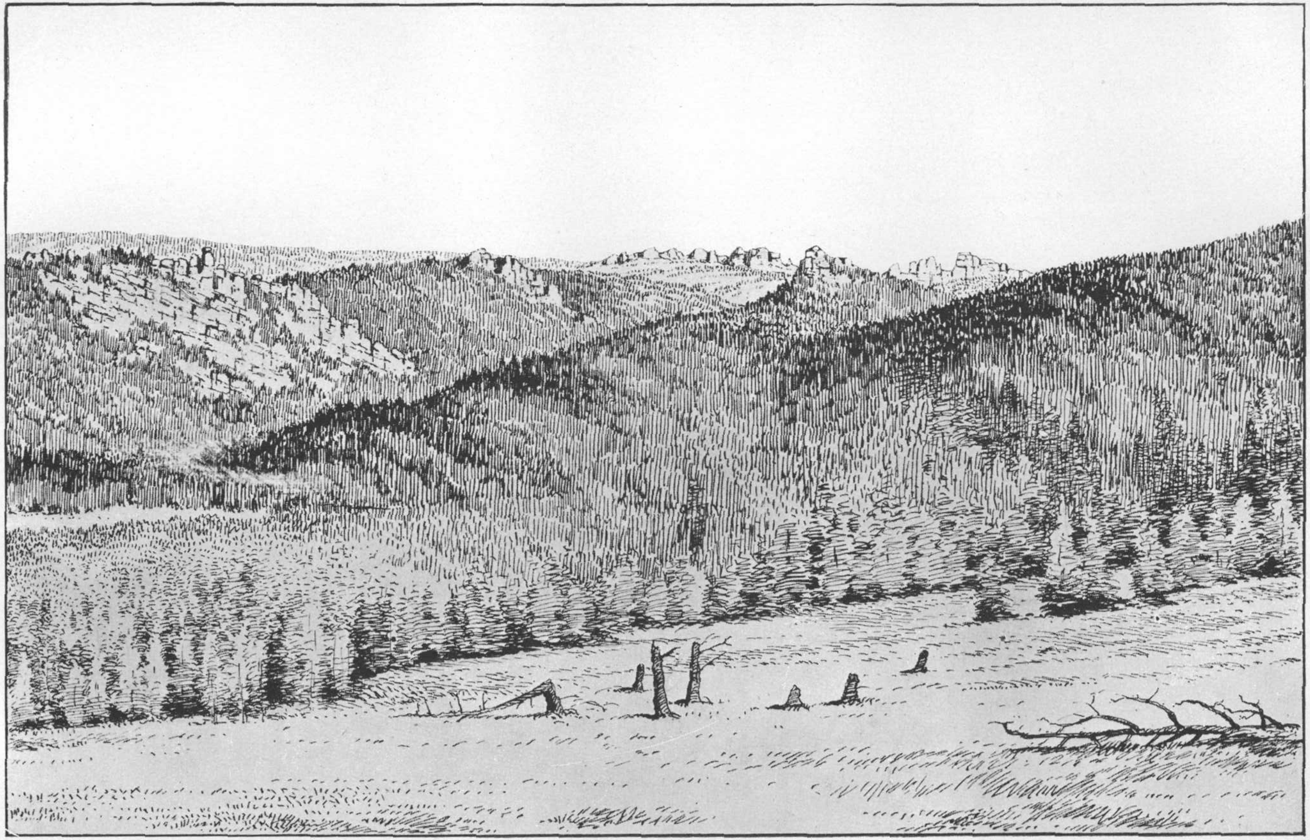
Buried valleys form an interesting feature of the northern slopes. Fourmile Creek is shown to possess a number of forks draining valleys cut back in the mountain side (see Pl. XV). The two westerly branches of the stream take their rise, however, in large springs but a short distance up these lateral valleys. Above these springs the valley still persists, but its bottom is smooth and flat, without any stream channel whatever. The adjacent slopes show no bluff walls such as characterize the lower end, but rise gently to the summit of the ridge. A few miles up these park-like valleys the meadows end abruptly against a heavily timbered moraine that completely fills the bottom. This is evidently the source of the bowlders occasionally seen below, and it is clear that the pre-Glacial gorge has been filled by the moraine, and lower down the finer débris carried by the glacial streams has filled up the old valley, whose present drainage flows through the glacial sands and rubbish to emerge near the main valley as springs. The moraine filling the valley and the débris or wash filling its lower part belong, however, to the retreating phase of the ice sheet, as the bowlders found at the Grasshopper mine and on the slopes east of the moraine prove an earlier and much greater thickness and extension of the ice.

Remnants of the moraine formed by a glacier flowing down Willow Creek, on the northwest side of the mountain, exist on the flat-topped hill west of the creek near the mouth of the canyon, and are also abundant on the synclinal area between Willow and Fourmile creeks, the drift consisting of bowlders of granite 3 to 6 feet across, with smaller drift of baked shale and of quartzite, the drift forming well-benched slopes. Owing, probably, to the ready erosion of the Mesozoic shales, this moraine has been nearly destroyed. This latter area may in part represent the drift left by a tongue of the Fourmile glacier, which overflowed its immediate valley near the site of the Grasshopper mine and flowed westward.

In reviewing the evidences of glaciation at Castle Mountain, it appears that the glacial streams occupied preexisting stream valleys, and that glacial erosion consisted chiefly in the removal of weathered material from the upper slopes, mainly from the granite area. No larger accumulations of assorted drift occur. The morainal deposits consist of a heterogeneous gathering of bowlders left as a mantle over the flat-topped ridges between stream courses and as benched slopes—the lateral moraines of the diminishing glacier. Terminal moraines are not differentiated. The morainal mantle is in part of terminal and in part of lateral origin.

The maximum extension of the ice is, of course, indicated by the lowest level at which glacial drift is found. Successive phases of the

TERMINAL MORAINE ON ALIBAUGH CREEK, NEAR TOWN OF CASTLE.



GORGE OF WEST FOURMILE CREEK.

melting ice sheet are marked by terrace lines upon the valley slopes. There is, however, one feature that deserves comment. The moraine front (pictured in Pl. XIII) is the terminal heaping of an ice stream coming from the large amphitheaters on the south side of the mountain summit. The recent aspect of the moraine is in marked contrast to the appearance of the adjacent bowlder moraines previously noted. It fills the drainage valley and marks the front of an area in which the glacial rock-polishing and other evidences of glaciation are remarkably fresh and well-preserved. Both the contrast in appearance and the relative position of this moraine, with the morainal remains found on the adjacent slopes, show that they are of very different age. The same evidence is presented in the moraine on the head of the west branch of Fourmile Creek. Those moraines found in the upper part of the valleys of Fourmile Creek, noted in the mention of buried valleys, indicate a renewal of glacial activity after a long period of decline. The accumulations are of very recent aspect, and show a period of stability during which the ice maintained a nearly constant front.

These facts clearly indicate two periods of glaciation, one of which is much older than the other, the later being of much less severity. Although in this particular region no interglacial deposits have been found, the facts just noted are in accord with observations made elsewhere in the province, and in entire accord with the observations of Dr. Dawson and other observers in the Rocky Mountain region of Canada,[1] where the observations show that the second period of glaciation was comparatively mild and the glaciers relatively small and insignificant during the second maximum of glaciation of the cordillera.

[1] Trans. Royal Soc. Canada, Vol. VIII, Sec. IV, 1890, p. 25 et seq.

CHAPTER X.

ECONOMIC GEOLOGY.

COAL.

CHECKERBOARD CREEK.

A thin seam of coal occurring beneath the Dakota quartzite near the forks of Checkerboard Creek has been mined in a small way for Messrs. Spencer, Main & Heitmann, of White Sulphur Springs. The seam is hardly thick enough, or the product of sufficiently high grade, to warrant working under ordinary circumstances; but owing to the distance of White Sulphur Springs from the railroad the cost of transportation of coal from other points has been prohibitive, and this seam furnished the only available source of supply.

WARM SPRING CREEK.

On the southern side of the mountain, where the Cretaceous rocks cover a large area, it may be confidently expected that coal seams will be discovered and developed at a number of localities. The most favorable coal-bearing horizon for prospecting is the Laramie, whose light-colored sandstones and gray shales lie in contact with the dark-colored beds of the Livingston. At the mouth of Warm Spring Creek a coal seam has been exposed. The seam is of sufficient thickness and purity to be workable, but the attitude is not favorable, the beds being vertical and the exposure but a few feet above probable water level. The outcropping sandstones can, however, be traced up the slopes southward, and the area will furnish an abundance of fuel when the demand warrants exploitation.

A seam of impure coal is also found above the charcoal kilns, on Warm Spring Creek, where it is close to the wall of massive, white, heavy-bedded limestone. It is too impure for fuel, however.

Coal seams have also been located at the Doucet ranch at Warm Spring Creek, above the main Castle road, but the material is bony and of little value as a fuel, though it has been learned that small quantities have been taken out and sold in Castle. The bed is 5 feet thick, dips from 40° to 90°, has a strike northwest, and occurs in a series of grits and impure sandstones of dark-gray or greenish color. The sandstone over the seam is formed of angular grains and resembles the volcanic grits of the Livingston formation. On the bench west of the stream the seam has been opened by a shallow shaft, but the quality is too poor to warrant working.

A short distance to the northeast the same seam occurs near an eastern branch of the creek, but is not workable. It is here associated with a highly ferruginous sandstone that has been quarried as a flux for the smelter. Coal is also found on the ridge west of Robinson Creek, southeast of Castle, but the seam is too impure to work.

POLISHING POWDER.

The volcanic dust forming the tuff beds of Castle Mountain, and of which a large part of the lake-bed strata consist, are worthy of notice as of economic value. This dust consists of fine, angular particles of volcanic glass. This material is useful as an abrasive, and could be used for polishing wood, stone, and metallic surfaces, and for making scouring soap.

MINERAL SPRINGS.

The White Sulphur Hot Springs, from which the county seat takes its name, are situated on the bench land south of Smith River, at the northwest base of Castle Mountain. The springs, formerly called Brewers Springs, have been known for many years and have acquired a considerable local reputation for their therapeutic properties, the water being largely used internally, as well as for bathing purposes.

The waters, which issue in considerable volume from a number of openings, are quite clear, but possess a strong odor of sulphuretted hydrogen. The temperature ranges from 103° to 125° F. (40° to 57° C.). Algæ growing in the springs near the vents are thickly coated with sulphur, forming delicate yellow skeins of soft, silky filaments that oscillate in the rapid-flowing streams. Farther from the source orange and green algæ are also found in some of the springs.

The springs are owned by Mr. Hirshfield, of Helena, and several acres of land about them are fenced in and reserved as a public park. A comfortable brick bath house has been built, with large pools, in which the water is a delicate opal blue from the suspended sulphur. The temperature in the baths is too high for comfort, unless the waters are allowed to stand and cool in the tank.

The waters are alkaline, saline, and sulphuretted. There are nine large springs and several seepages, whose combined flow is estimated at 13,000 gallons per hour. The water used for drinking purposes and to supply the public baths has a temperature of 123½° F. (51° C.).

The first analysis[1] (I) on page 150, made by Dr. R. B. Riggs in the laboratory of the United States Geological Survey, shows the composition of these waters.

The second analysis (II) is that published by the White Sulphur Springs Hotel Company.

[1] Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, 1885, p. 180.

Analysis of water of White Sulphur Springs, Montana.

I.

	Grams per liter.
Sodium carbonate	0.5571
Calcium carbonate	0.1280
Magnesium carbonate	0.0438
Sodium sulphate	0.4463
Sodium chloride	0.2460
Potassium	0.0807
Silica	0.0330
Sodium silicate	0.0194
Hydrogen sulphide	Trace.
Total	1.5543

II.

	Per cent.
Fixed salts	0.166
Sodium	0.05258
Magnesium	0.00178
Lime	0.00254
Potassium	0.00468
Chlorine	0.01782
Bromine	Trace.
Iodine	Trace.
Lithia	0.0008
Sesquioxide of iron	0.0007
Alumina	Trace.
Silica	0.00404
Carbonic acid	0.074
Sulphuric acid	0.02538

The springs issue from Miocene lake-bed deposits which conceal the geologic structure of the rocks below. The calcareous shales of the Belt formation outcrop within a few rods of them, however, in exposures along the bank of Smith River. The proximity of the Castle Mountain massif and the recency of volcanic activity at Volcano Butte render it probable, however, that the source of heat is connected with volcanic rocks rather than with the great fault of Willow Creek, which lies a couple of miles to the east. There are no deposits of siliceous sinter or of calcareous tufa. The marshy areas about the springs are white with an efflorescence of carbonate of soda, and the peculiar sulphurous odor of the springs and the marshy meadow itself are characteristic features of many hot-spring localities and readily recognizable signs of their proximity.

PRECIOUS METALS.

The Castle mining district was for some years regarded as the most promising silver-lead producing area of Montana. Notwithstanding the distance from the railroad—75 miles—and the high cost of transportation of coke and supplies, the Cumberland and Hensley smelters produced gold to the value of $16,550 and silver to the value of $36,355, in 1889.[1] In 1890 the Cumberland, the principal mine of the district, produced ores that yielded 500,000 pounds of argentiferous lead and over 20,000 ounces of silver.[2] The former was increased to 5,000,000 in 1891, making this mine the largest single producer of the State. The output fell to 300,000 pounds of silver lead in 1892,[3] when the mine was closed.

The ores of the district are largely argentiferous galenas, or their decomposition products, which require reduction by smelting, a process rendered expensive by the extraordinarily high cost of fuel. The district has, therefore, been one of the earliest to suffer by the reduced price of silver.

These conditions, together with the lack of cheap railroad transportation and the unsatisfactory showing of the ore bodies thus far developed by prospecting, have, in the past, made the district a very disappointing one. In spite of favorable geologic conditions, of promising surface indications, and of extensive prospecting, the only large ore body which has been found is that of the Cumberland.

CHARACTER OF ORE.

The ores consist of comparatively few minerals. Galena and its oxidation products—sulphate and carbonate of lead—constitute the chief ore minerals, together with copper and iron pyrites and an oxidized manganese mineral. These are described under the notes on the minerals of the district. The gangue is usually siliceous jasper, which occasionally passes into quartz.

DISTRIBUTION.

The following facts are noticed with regard to the distribution of the ore bodies of the district. The ores occur only in the sedimentary rocks that have been altered by the eruptive bosses of granite and diorite, and which form a zone of metamorphosed rocks about these eruptive masses. The deposits that have thus far proved valuable occur in the altered limestone, at the contact with dikes of porphyry or as ore bodies having no perceptibly direct connection with eruptive rocks. A number of prospects are located on decayed basic dikes. These have not in any instance, so far as known, shown any considerable amount of ore. The deposits thus far discovered in the altered Belt shales are not workable, though considerable prospecting has been done in such rocks.

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[1] Report Director of Mint for 1889.
[2] Idem, 1890.
[3] Report Director of Mint for 1892; Mineral Resources U. S. 1892, p. 124.

STRUCTURAL CONDITIONS.

Exploration of the Castle Mountain ore bodies has not been sufficiently thorough to develop any regular mode of occurrence, but from observations made by the writers it is evident that they belong to the class of ore pockets of galena and associated sulphides occurring in the altered zone of limestones adjacent to the main granite mass and generally connected with intrusions and offshoots of the granitic rock. It should be borne in mind, however, that the closing of the various mines has prevented underground explorations, and we are obliged to rely on the information furnished by the miners for the facts concerning the location of the ore bodies.

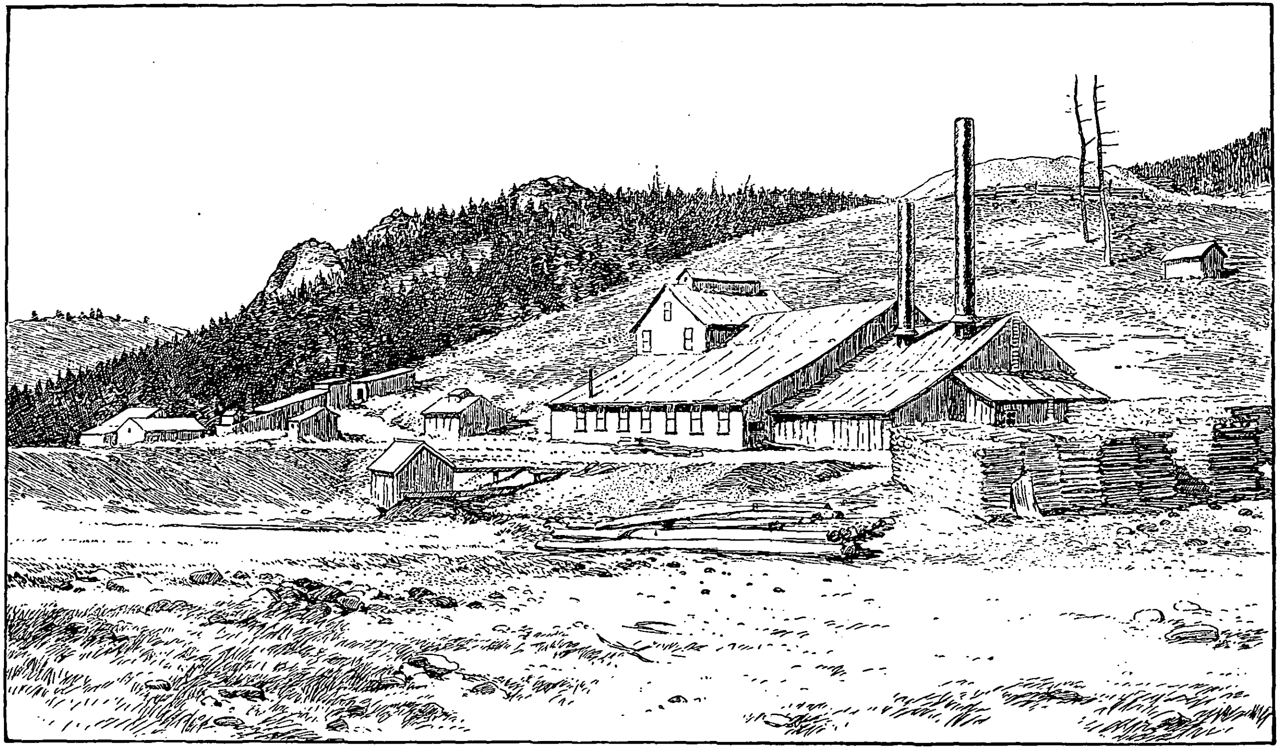
In general, it is noticed that throughout the Castle Mountain district the contact between the sedimentary rocks and intrusive masses of the igneous rocks is marked by more or less alteration, showing that the contact has afforded a passage for ascending vapors and mineral solutions. The nature of the decomposition seems to show that the vapors or mineral waters have been alkaline in character and deep-seated in origin, and none of the products of descending acid waters are found throughout the district. On the other hand, the deep alteration of the Cumberland ore body from galena, of which its lower portion is composed, to the carbonates and sulphates of lead is clearly due to the oxidation of the ore body.

The ore occurs in small, irregular bodies scattered through the limestones, so that the prospectors generally say that they are on a "bowlder" of ore and have not struck the ore body yet. The large size of the Cumberland deposit, which is a long, pod-shaped body, described later, led the early prospectors to believe that these small ore bodies were only detached fragments of the main ore mass, which they confidently expected to find on further exploration. In common phraseology the ore occurs in pockets in the limestone or near the contact of limestone and igneous rock. So far as the writers' observations could be carried, they show that the general conditions of ore deposition are those established by Emmons for the Leadville deposits, which have since proved so generally applicable. Briefly stated, these are as follows:

1. The ores were deposited from aqueous solution.
2. They were deposited as sulphides.
3. The process was a replacement of limestone by ore—a metasomatic interchange of rock by ore.
4. The mineral solutions or ore-carrying currents followed bedding planes or planes of fracture which were or were not filled by dike material.

NOTES ON THE MINES.

The Cumberland.—This is the largest and most important mine of the region. The history of the Cumberland is that of the Castle district itself. Discovered in 1884, it was in 1891 the largest single producer



CUMBERLAND MINE.

of lead ores in the State. Complete mining and smelting works were soon erected (see Pl. XVI) and every preparation was made for successful working. The high cost of smelting the ores, however, led to the shutting down of the smelting plant, as it was considered wise to await the building of a railroad and ship the ores rather than incur the expense of treatment at the mine. The Cumberland Mining and Smelting Company was, moreover, a stock company, and diverse interests, each fearful of the other, sought to control the property. In 1892 Mr. J. Kennedy Tod, of New York City, purchased control, and a careful investigation of the mine and its ore reserves was made by the well-known expert, W. B. Parsons. Operations were, however, suspended early in 1893, after the expenditure of considerable amounts of money for further development and exploration of the property. It was generally understood at that time that a railroad would soon be built connecting with one of the transcontinental lines, but the impending financial panic, combined with the low price of silver, prevented the realization of this hope, and the district was in 1894 practically deserted save by a few sanguine miners who remained, hoping each month would see a change for the better and the building of the promised railroad.

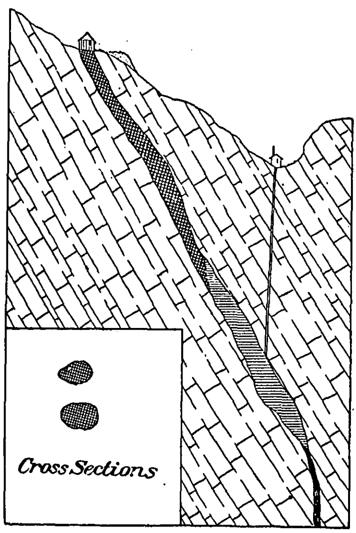


FIG. 9.—Diagram of ore body of Cumberland mine, Castle Mountain.

The ore body is a remarkably regular, pod-shaped mass, with elliptical cross section, dipping at an angle of approximately 60°, its greatest width roughly conforming to the bedding of the limestones in which it occurs. The accompanying figure (fig. 9) shows the relations of the ore body to the limestone and to the granite mass. The early workings were started at the outcrop, an inclined shaft being sunk upon the ore body and a considerable quantity of ore extracted. Later a perpendicular shaft was sunk from the slopes near the stream bottom to the east, the shaft reaching the ore body at about 500 feet below its outcrop. Development has progressed until the extent of the ore is now well known. Upraises extend through to the surface, and winzes have followed down the lead, which ends not far below the 500-foot level, the ore passing into a narrow zone of pyritiferous vein matter lying between a porphyry dike and the limestone. A crosscut at the 500-foot level runs westward to the granite mass, cutting two dikes of greatly decomposed porphyry and tapping the variable zone of decomposed rock carrying pyrite that marks the contact between the granite mass and the upturned sedimentaries. The observations seem to indicate that the ore body has been formed by solutions ascending along the contact between the porphyrite dike and the limestones. The contact between the limestones and the granite mass is shown by the underground workings to have a dip of about 65° under the limestones. In the lower workings the sedimentary rocks have been much more greatly altered than they have at the surface, a condition which is believed to be due to the proximity of the main mass of granite and to the number of dikes or intrusive sheets which are offshoots from the granite but which do not reach the present surface. Pl. XVII shows the situation of the mine with reference to the surrounding slopes of limestone and granite.

Great Eastern.—Ore body of galena on contact between porphyry and brecciated limestone. Improved by shaft 100 feet deep and a short drift. Horse-whim hoist.

Yellowstone.—This is one of the oldest and largest mines of the district. It is situated on a spur of the mountain between Hensley and Hamilton creeks, at an elevation of 7,200 feet. The surface rock is porphyry, part of an exposed intrusive sheet. The material on the dump heap shows that the ore body is on a contact between white crystalline limestone and the porphyry. A two-compartment shaft, with bucket hoist, has been sunk about 300 feet deep, but owing to the water in the mine the workings could not be visited. There is said, however, to be about 200 feet of drifting. The company have well-constructed buildings containing engine and boilers and a pumping outfit, and a number of buildings for offices, boarding houses, etc.

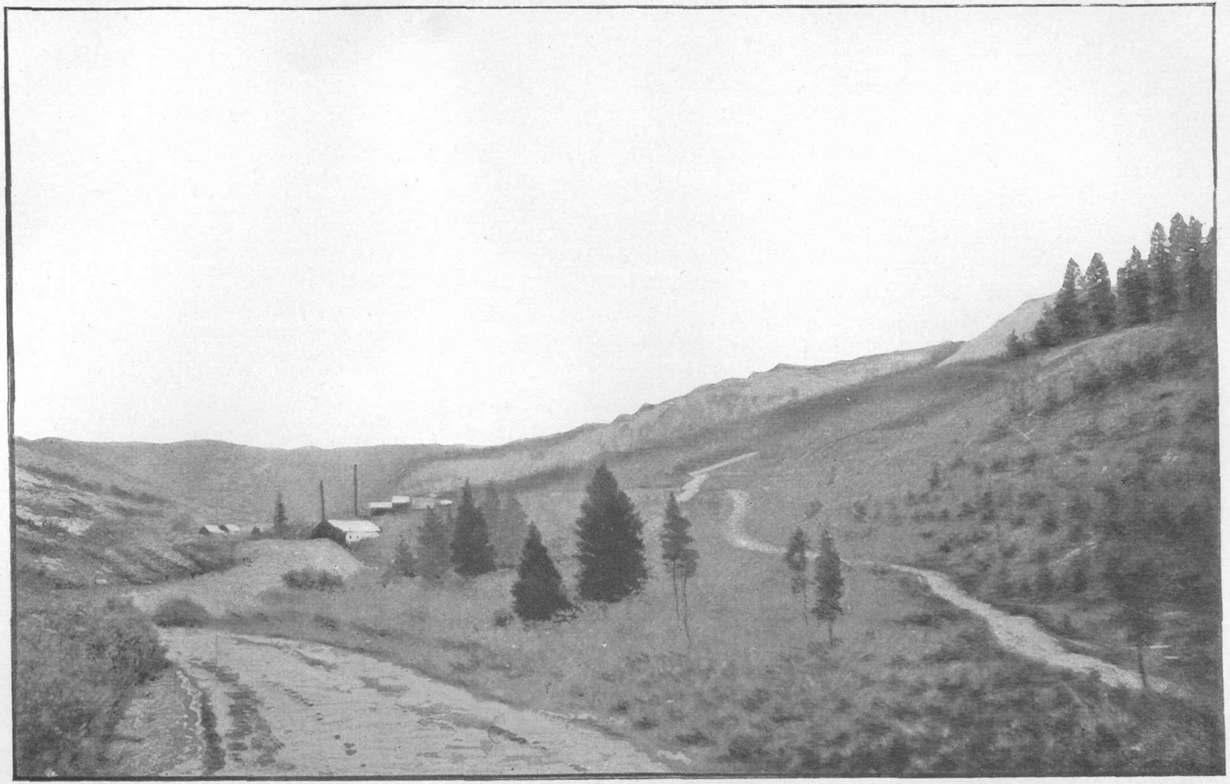
The California is a mine showing good quality of ore, but has not been developed sufficiently to show the extent of the ore body.

The Blackhawk group of mines includes the Legal Tender, Judge, Iron Chief, Blackhawk, Bondholder, Alice, and many minor claims. These claims are in the zone of metamorphosed rock east of the diorite intrusion.

Blackhawk.—The workings include about 200 feet of east and west drifting and a 100-foot south crosscut. The shaft is 130 feet deep, the levels running out at a depth of 100 feet. The water stopped further working. The ore body is said to be large, and to lie between a porphyry wall and the altered limestones, and to have a dip of 50°. Massive black manganiferous ore, running about 5 to 15 ounces of silver.

Legal Tender.—This mine is said to have been sunk on a small ore body that has not yet been carefully explored. There is a 200-foot shaft with crosscuts at right angles to ore (i. e., east and west). The ore is a mixture of galena and carbonate. The mine has a complete outfit of hoists and pumping machinery, and a 3-inch pump for handling the water, but the shaft is not well built or proportioned.

The Judge is situated on the flat-topped ridge east of the settlement of Blackhawk, in metamorphosed Cambrian limestone. It is provided with a two-compartment shaft, 240 feet deep, and some 40 to 50 feet of



CUMBERLAND MINE, FROM THE NORTH.

crosscutting has been done, the ore being hoisted in a bucket. The mine is still being worked (1894) by two men, who take out the ore, sort and sack it, and ship it by wagons to White Sulphur Springs. The ore body is said to have outcropped at the surface. It is 15 feet wide, but pay ore forms a chute from 8 inches to 4 feet wide and 20 feet long.

Bondholder.—This is the name of a mine useful only as a means of working the adjacent claims, as it has struck but a small body of manganiferous ore. A crosscut connects the shaft with the workings of the Alice. The outfit, consisting of hoist, pumping machinery, etc., probably ranks second to that of the Cumberland.

Alice.—Prospect shaft, 85 feet deep, shows a body of ore 3 by 6 feet in cross section.

Iron Chief.—Ferruginous outcrop. Ore said to yield 50 per cent lead and 20 to 30 ounces of silver. Two-compartment shaft, 250 feet deep, with outfit of bucket hoist, 40-horsepower engine, boilers, etc.

Hidden Treasure.—Galena and carbonate ore in small body. Prospect shaft, 200 feet deep, with crosscut. No machinery save horsewhim.

On the high bench between the headwaters of Warm Spring and Alibaugh creeks there are several prospects, among them the Princess, American, and Rattler claims. A little high-grade ore has been found, but no bodies of sufficient size to warrant development have thus far been discovered, nor do the conditions appear favorable at this point.

On the open grassy mountain spur between the diorite and granite intrusions there are a number of claims located. The rocks are altered Belt shales cut by intrusive sheets of porphyry and basic dikes, a number of the claims being located upon the decomposed outcroppings of the latter.

Tip-Top, the highest claim on the mountain, is located on a contact of dense, baked Belt shale and a decayed minette dike. The shaft is 160 feet deep and as yet shows but little ore. The contact rocks contain epidote and other minerals.

Little May, located January 3, 1893, shows frothy-white and ferruginous-brown quartz, with brown jasper stained with ore. No workable ore seen at dump. The ore occurs as chalcopyrite, a decomposed minette dike cutting the Belt shales and porphyry sheets.

Several other prospects were examined on the ridges, but none showing workings sufficient to enable one to judge of the size and character of the ore bodies, though scattered bits of copper-stained ore were noticed at several prospect pits. One or two claims have been located on pyritiferous seams in the diorite mass, though but little work has been done and the ore extracted looks unpromising. The principal claims are those back (i. e., west) of Blackhawk settlement and on the mesa between Blackhawk and Robinson.

Grasshopper mine.—Wherever the white Paleozoic limestones are found in the contact zone about the granite mass the locality is marked by prospect pits. This is particularly the case along the northern flanks of the mountain, where mine cabins and dump heaps are prominent features of the landscape. On the low limestone ridge east of the most westerly branch of Fourmile Creek there are several of these prospects in the slightly altered rocks, and on the divide between this stream and Willow Creek is the claim known as the Grasshopper mine. The ore is manganiferous, with some galena, and occurs in a pocket in slightly altered black Silurian limestones. A shaft house has been erected over the mine, and several cabins are located near by. Pl. XV shows the upper gorge of Fourmile Creek, from a photograph taken at the mine, and shows the heavily forested slopes, steep gorges, and crags of the granite, which are in such strong contrast to the limestone areas.

COPPER.

The copper veins of the region north of Castle Mountain have been known for many years. As early as 1867 they attracted the attention of the pioneer fortune-hunters of the State, and in 1874, when seen by Grinnell and Dana, there was a shaft 40 feet deep on one of the claims, two men taking out ore to be shipped by steamer down the Missouri for smelting at Baltimore. For many years maps of Montana have shown the name of Copperopolis, a supposed settlement on the site of these veins, which really consists now, as it did in 1875, of a mining shaft and deserted log cabin. Notwithstanding this long period during which these reefs have been known, mining has in the interval been confined to mere surface digging or "gophering" of the deposits. A few pits have been sunk for the purpose of holding the claims, but without any attempt to gain a better knowledge of the ore bodies. In consequence as little is known to-day as in 1874. There are, in fact, no mines whatever; a number of prospects are located, and a few claims have been patented, but the place is all but totally abandoned.

The copper veins are all in the shales of the Belt formation. At a number of places this formation has been found to be penetrated by small fissure veins that are sometimes on shear planes. On Sixteenmile Creek, at the south end of the Big Belt Range, as at the present locality and on Upper Spring Creek, the shales are traversed by narrow veins of quartz and calcite carrying cupriferous sulphurets, with oxidized minerals at the surface. Nowhere do these veins pass upward into the overlying formations, for which reason they must be regarded as antedating Middle Cambrian times. Their narrowness is perhaps due to the fact that they are the roots or lower parts of veins whose upper and wider parts have been worn off during the long processes of degradation that have removed thousands of feet of rock and produced the present features of the land.

The ores, if only found in sufficient quantity, are rich enough to warrant exploitation even in this remote location, but the openings thus far do not expose enough to warrant any favorable predictions as to the value of such development.

MINING CLAIMS.

Copperopolis.—The veins here are fracture planes in Belt shales. In the coulée these shales are of pinkish-lavender color and dip 20° into the hill.

The following claims are located along the outcrop of one of the veins: Copper Duke, now known as the Virginia; the Ohio, a patented claim, covering 2,200 by 100 feet, and the vein here having a trend of S. 57° 30′′ E.; the Albany; and the Standard.

The St. John is a patented claim 2,200 by 100 feet. The Northern Pacific lies to the northeast, and the Darling Fraction to the southwest.

Nearing Copper Creek the lead bends, and the Hecla and East Hecla are located upon it, the ledge running S. 69° E. and crossing the creek diagonally.

Calumet claim has a trend of N. 75° E. magnetic. It is a calcite claim, dipping 60° to northwest, and is in gray shales reddened at surface. The lead is 4 feet wide where opened by shallow pit, and shows crushed shales impregnated with copper stain.

The Northern Pacific is an old mine, opened in 1867, when ore was shipped down the Missouri River. The ore is said to average 45 per cent and to run as high as 75 per cent copper. The drift and shaft on this claim have both caved in, and though there are several openings but a few feet apart along the lead, it is not well exposed. The lode matter is largely calcite, and the width 10 feet, the calcite being streaked with ore.

The Darling Fraction is opened by a shaft 75 feet deep, with a log shaft house. It shows at best 4 feet of sulphurets. A little ore was shipped from here four or five years ago, and bags of it now lie in the shaft house. East of this claim the vein is opened by two pits about 30 feet deep.

The Copper Duke, now called the Virginia, is a claim on the hillside, a half mile from these. The ore is a sheared shale impregnated with quartz, forming a seam 3 feet wide of good-looking oxidized ore.

On the slopes north of the Musselshell, northeast of the stage station, there are a couple of openings on narrow seams. At one the shaft is 30 feet deep, 3 by 6 feet, and timbered. The lead is 2 feet wide at the outcrop, has well-defined, clean walls, and shows quartz, rust-stained on cracks, with gray copper and pyrite; a rather lean ore. The lead runs east and west magnetic, and lies in soft gray shales. The slopes of the hill are bare, rounded, and smooth.

Below the mouth of Checkerboard Creek there are a few copper-stained leads in the slopes north of the Musselshell; trend N. 65° E., hade 75° N., 15 to 16 inches wide. Ore pyritic, occurring in a crushed, soft gray shale along a shear zone. This is owned by J. W. Hinckley.

The Richmond is another lead, trends S. 65° W., is mineralized, shear plane in clay; sulphurets, malachite and azurite. Shaft, 30 feet deep.

In the Belt area forming the mountain basin of Spring Creek the shales are crossed by narrow ledges stained with copper; not of sufficient importance to warrant development.

CHAPTER XI.

BRIEF NOTES ON MINERALS OF THE CASTLE MOUNTAIN DISTRICT.

The following list includes only those minerals which have been seen in the progress of the survey or have been reported by trustworthy observers. It does not, of course, pretend to be in any way complete. To make a thorough examination of the various mines, ore heaps, and dumps, would have required far more time than would have been warranted by the results that could have been obtained. It is therefore to be expected that in time this list will be greatly enlarged.

ALBITE: $NaAlSi_3O_8$. This feldspar has been observed only as a secondary rock constituent in the porphyry.

ANGLESITE: $PbSO_4$. Lead sulphate has not been observed by the writers, but is stated to occur at several mines. Occurs associated with cerussite and is produced by the oxidation of the galena (PbS), the chief ore of the district.

ANORTHOCLASE: (NaK) $AlSi_3O_8$. This feldspar is one of the chief constituents of the granite, as mentioned in chapter VI, pages 82–83.

APATITE: $Ca(ClF)Ca_4(PO)_3$. So far as observed, occurs only as minute crystals scattered through the igneous rocks.

AZURITE: $2CuCO_3, Cu(OH)_2$. The blue carbonate of copper is found in several places but not in large quantities. The prospect shafts at Copperopolis show it in massive form mixed with malachite and chrysocolla. At the Richmond prospect shaft, east of the Musselshell Canyon, it occurs in small crystals with malachite. The crystal faces are apt to be dull and rounded, and the crystals are hence unsuited for measurement. They are composed chiefly of the faces c (001), σ (101), and a (100).

BARITE: $BaSO_4$. Barium sulphate or heavy spar is a rather common mineral in many of the ore veins and deposits, and is especially associated with the copper ores, of which it often forms the gangue. Good crystals not observed.

BIOTITE: This black mica exists only as a rock constituent in small crystals. The variety called phlogopite, poor in iron or free from it, occurs, as mentioned on page 93, as a contact mineral in the limestones at Blackhawk. It strikingly resembles the same mineral from Edwards, N. Y. It occurs in plates an inch or (at times) more in diameter.

CALCITE: $CaCO_3$. Drusy cavities in the limestones are frequently lined with crystals of the carbonate of lime. It is almost invariably crystallized in the common scaleneohedron v 1^3 $(21\bar{3}1)$; occurs also in cavities in the ore veins and in amygdules in the vesicular basalt of Volcano Butte.

CERUSSITE: $PbCO_3$. The carbonate of lead is a very common constituent of the ore bodies in the limestone areas. It occurs as an alteration product of the galena, and is commonly associated with it. Splendid crystallizations are found at the Judge Mine at Blackhawk, though, unfortunately, at the time of the writers' visit, as active work was not being carried on, they were unable to see or secure some of the best. Nevertheless, through the courtesy of Mr. Davis, the foreman of the mine, some excellent material was obtained. This has been studied under the writers' direction by Mr. J. H. Pratt,[1] of the Sheffield Scientific School, and the results of his investigation are here given:

"The specimens are in the form of rough masses, at times as large as one's fist,

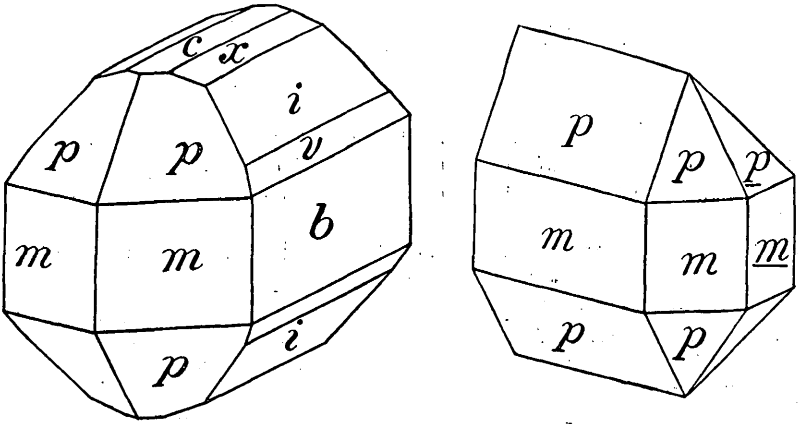
[1] See also Am. Jour. Sci., Vol. XLVIII, 1894, p. 212.

showing an occasional broad crystal face. These fragments are remarkably clear and free from foreign inclusions. Attached to these are small, bright crystals, both simple and twinned. Their faces are generally smooth, giving very good reflections of the signal when measured on the reflecting goniometer.

"Specimens of the simple crystals, which are represented in fig. 10, were found so attached to the rest of the mineral that the faces on both ends of the lateral axes were developed and could be measured. The forms observed on them were

b (010) *i-ĭ*	*i* (021) 2-*ĭ*
c (001) O	*v* (031) 3-*ĭ*
m(110) I	*p* (111) 1
x (012) $\frac{1}{2}$-*ĭ*	

"The greater part of the crystals observed, however, were twinned, the twinning following the common method in which the twinning plane is the unit prism *m*, I, (110). These crystals are represented by fig. 10 *b*. As shown in



a *b*

FIG. 10.—Cerussite crystals. *a*, simple crystal; *b*, crystal twinned on 110. Measured and drawn by J. H. Pratt.

the figure, they are extended in the direction of the twinning plane, and are so attached against the smooth surfaces of larger crystals that the twinned pinacoids at the other end are wholly wanting, the crystal being cut square off at this point, as in the figure. They resemble strongly the untwinned ones. The following table shows the identification of the forms by calculated and measured angles.

"For obtaining the calculated angles the elements of Koksharov[1] have been used, in which

$$\breve{a} : \bar{b} : \grave{c} = 0.609968 : 1 : 0.723002.$$

		Calculated.	Measured.		
		° ′ ″	° ′	° ′	° ′
m∧*m*	110∧1$\bar{1}$0	62 45 50	62 45	62 45	62 45$\frac{1}{2}$
m∧*p*	110∧111	35 46	35 46	35 45	35 46$\frac{1}{2}$
p∧*p*	111∧1$\bar{1}$1	49 59 30	49 58	49 57$\frac{1}{2}$	
c∧*x*	001∧012	19 52 30	19 49	19 51	
c∧*i*	001∧021	55 20	55 19	55 19	
c∧*v*	001∧031	65 15	65 9	65 11	
m∧*m*	110∧110 (twin)	54 28 30	54 28	54 29	54 26
m∧*p*	110∧111 (twin)	43 36 30	43 39$\frac{1}{2}$	29	

[1]As given in Dana's Mineralogy, 6th ed., 1892, p. 286.

CHALCOPYRITE: $CuFeS_2$. Copper pyrites occur in a number of the leads, and in the Copperopolis prospects is the chief ore after the water level is reached. The other ores of copper are products of its alteration. Distinct crystals have not been observed.

CHLORITE: This greenish micaceous mineral is a common alteration product of several silicate minerals. Occurs abundantly at the Little May prospect back of Robinson, disseminated as a scaly product in the earthy, decomposed material on the dump, which is stained by the alteration of copper ores and appears to be a greatly decomposed basic rock of lamprophyre character. Occurs also as a common alteration product in many of the igneous rocks, giving them their greenish tone.

CHRYSOCOLLA: The silicate of copper is found, with other copper ores, at many points in the district. Excellent specimens occur at Copperopolis, and on Sixteenmile Creek at the Copperopolis lead are beautiful examples associated with barite, quartz, etc.

EPIDOTE: A common product of the alteration of the Belt shales by the intrusion of the Castle Mountain granite. Occurs in thin seams usually coating joint faces of the rock masses of the characteristic yellowish-green color. Small crystals have been observed, but not of sufficient size or excellence to merit further description.

FLUORITE: Occurs as a rock-forming mineral in the quartz-porphyry of Fourmile Creek, as mentioned on page 99. Is reported also as occurring in the form of a gangue mineral in some of the leads of the district, but was not observed by the writers.

GALENA: PbS. The sulphuret of lead is the chief ore of the district, as described on page 151. Is generally massive, but was observed at times in the usual cubic crystals.

GARNET: The only occurrence of this mineral seen by the writers was in the metamorphosed limestone near Blackhawk. This was the lime-alumina garnet, grossularite, of a pale oil-green color, usually massive, but at times in distinct dodecahedrons, associated with vesuvianite and white phlogopite. (See p. 93.)

GYPSUM: $CaSO_4.2H_2O$. The hydrated sulphate of lime occurs in thin seams in the Belt Mountain rocks about 4 miles north of White Sulphur Springs. Is fibrous in structure.

HEMATITE: Fe_2O_3. This ore of iron does not occur to the writers' knowledge in any quantity in the district, though a common coloring material in many of the slates and shales.

KAOLINITE: Clay is found at a number of places in the district, but not pure enough to become a commercial product.

LABRADORITE: Occurs only as a rock-forming mineral in the dark-colored igneous rocks of basaltic character.

LIMONITE: $2F_2O_3$, $3H_2O$. This ore of iron occurs as an alteration product in many of the ore veins, and is disseminated through the stratified rocks, though nowhere occurring in quantity.

MAGNETITE: Fe_3O_4. This iron ore occurs as a rock-forming mineral and is the chief constituent of the black sandstone occurring with the impure seam of coal found on Warm Spring Creek (see p. 149), where it was mined as a flux for the Castle smelters.

MALACHITE: $CuCO_3.Cu(OH)_2$. The green carbonate of copper is a common mineral, being found in many of the mines and prospects, and especially at Copperopolis. On Sixteenmile Creek at the Copperopolis lode it occurs in distinct crystals; elsewhere it is usually massive. A large amount of useless labor has been performed by the prospectors in this region from inability to realize how large an amount of rock may be colored vividly green by a very small quantity of this mineral. Like the azurite, it results from the alteration of copper pyrites.

MINIUM: Pb_3O_4. This rare mineral, the red oxide of lead, occurs at the Little Jumbo mine near Castle. It is found in pulverulent earthy masses of a vivid red color. It occurs at or near the surface and has been supposed to be an alteration product of cerussite from forest fires, an origin which must be regarded as doubtful.

MUSCOVITE: This mica occurs as an alteration product of biotite as a rock-forming mineral. Has not been otherwise observed.

OLIGOCLASE: Found only as a constituent of the igneous rocks.

ORTHOCLASE: See page 83.

PHLOGOPITE: See Biotite.

PYRITE: FeS_2. Iron pyrite is an extremely common mineral in most of the mines in the district. Was observed in small but excellent crystals in the prospect shafts sunk in the diorite on the hill southwest of Blackhawk. The crystals show the usual striated combination of the cube and pyritohedron.

PYROLUSITE: MnO_2. The black oxide of manganese occurs in the hill north of Blackhawk, where it forms an ore body of undetermined size. It has been mined below the Judge and Legal Tender mines, the rock in which it occurs being thought suitable for fluxing. Occurs in soft earthy forms, and massive distinct crystals were not observed.

PYROXENE: As has been previously stated, pyroxene occurs on upper Bonanza Creek as a product of the metamorphism of the Cambrian limestone by the intrusion

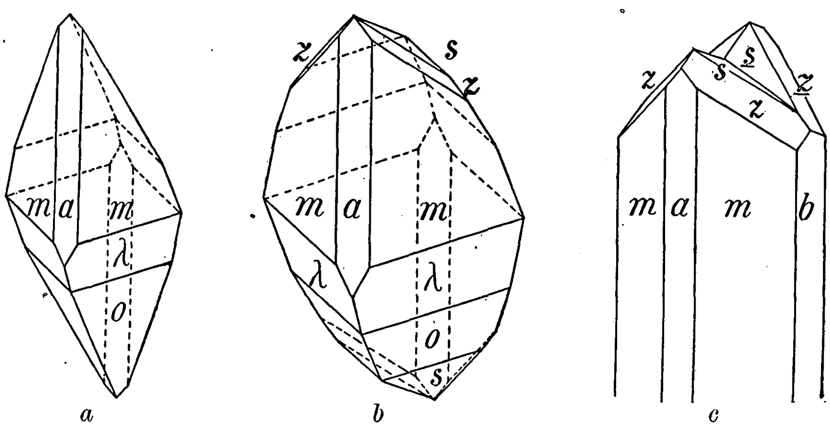


FIG. 11.—Pyroxene crystals of altered limestone.

of the diorite mass. A prospect shaft on the hillside south of the stream, about a mile below Blackhawk, shows excellent material. The limestone is completely converted into masses of pyroxene and calcite at this point. In some of these masses the crystals of pyroxene are so thickly embedded in the calcite that at first glance the rock appears as if completely made of them.

The crystals are usually small, not exceeding 1 centimeter in length, except where projecting into a cavity. In color they are dark-green, and are clearly of the diopside variety. The faces are apt to be dull in luster, as is so often the case in examples embedded in calcite. Except where crowded so thickly together as to interfere with one another's growth, they are usually symmetrically developed, both ends being present, and they have, as a rule, the habit shown in fig. 11 *a*. At times, however, they are stouter and show a greater complexity of forms, as illustrated in fig. 11 *b*. It often happens, indeed, that in such crystals the zone of pyramids has its faces curved and rounds down into the prism, the crystal then assuming a seed-like form. A few instances of twinned crystals were noted, which were, however, of quite different habit from the above. One of them is shown in fig. 11 *c*.

The following forms have been identified on these crystals:

a 100	*s* $11\bar{1}$
b 010	*o* $22\bar{1}$
m 110	*λ* $33\bar{1}$
z 021	

Of these, the form $\lambda(33\bar{1})$ is by no means common. The faces of these crystals do not as a rule reflect light well when placed on the reflecting goniometer, giving blurred and confused reflections, owing to minute pitting, etc. The measurements are, however, sufficiently accurate to identify the forms, as may be seen by the following table of calculated and measured angles.

		Calculated.	Measured.	
		° ′	° ′	° ′
$a \wedge m$	$100 \wedge 110$	46 25	46 26	46 41
$m \wedge z$	$110 \wedge 021$	48 6	47 55	
$o \wedge o$	$22\bar{1} \wedge 2\bar{2}\bar{1}$	84 11	84 27	
$\lambda \wedge \lambda$	$33\bar{1} \wedge 3\bar{3}\bar{1}$	91 35	91 48	
$m \wedge \lambda$	$110 \wedge 33\bar{1}$	24 27	24 43	24 18
$m \wedge o$	$110 \wedge 22\bar{1}$	35 29	35 03	34 51
$m \wedge s$	$110 \wedge 11\bar{1}$	58 48	58 20	

QUARTZ: SiO_2. Is of so common occurrence that it needs no further mention. Large, well-formed crystals have not been observed.

RUTILE: TiO_2. Only as a rock constituent.

SERPENTINE: Only as a rock constituent.

TOURMALINE: Occurs only as a rock constituent.

VESUVIANITE: This silicate occurs with the garnet previously mentioned, in brownish grains and masses showing an occasional crystal face, but not in distinct crystals. (See p. 93.)

WULFENITE: $PbMoO_4$. This mineral occurs at the California mine, and the writers are indebted to the courtesy of Prof. F. W. Traphagen, of Bozeman, Mont., for the opportunity of examining a specimen. It occurs in cavities in massive galena and is of the usual red-orange color. The luster of the crystal faces is dull, as if caused by superficial alteration. The crystals are octahedral in habit, being composed of the unit pyramid *n*(111) alone, and the largest seen was nearly half an inch long.

INDEX.

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